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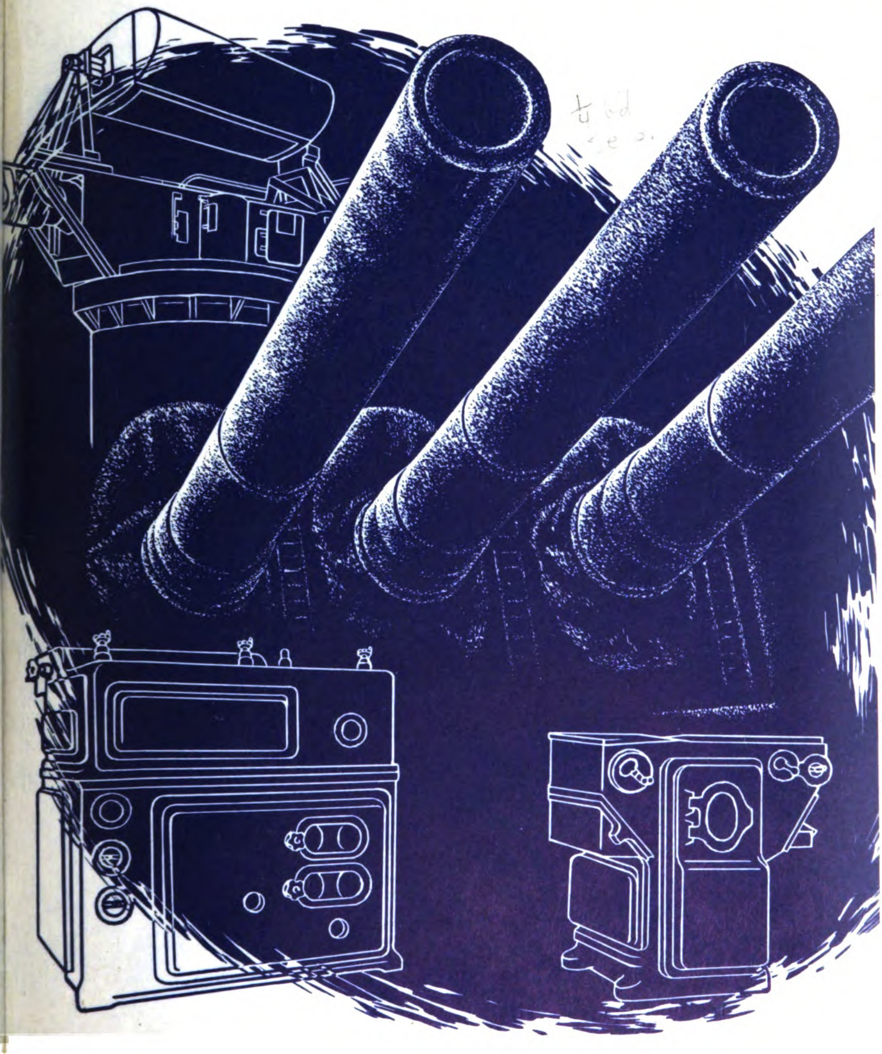

FIRE CONTROL TECHNICIAN 2

NAVPERS 10174

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FIRE CONTROL TECHNICIAN 2

Prepared by

U.S. BUREAU OF NAVAL PERSONNEL

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

Doc.
Coll

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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PREFACE

This book is written to aid the Fire Control Technician 3 to prepare for advancement to the rate of Fire Control Technician 2. The minimum qualifications required for advancement to FT2, as listed in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068, are in an appendix at the back of this book. Since examinations for advancement are based on these qualifications, it is suggested that they be referred to frequently while studying this course and otherwise preparing for the examination.

Before beginning this manual, the reader needs a good grasp of the materials contained in the basic Navy Training Courses in *Mathematics* (NavPers 10069–A and 10070–A), and of *Basic Electricity* (NavPers 10086) and *Basic Electronics* (NavPers 10087). The material in this course is based on fire-control equipment that the FT3 is most likely to encounter. It must be remembered, however, that this book must not be substituted for specific equipment publications, such as the OD's and OP's of the Bureau of Ordnance, when servicing equipment. It is the purpose of this Navy Training Course to teach those principles of fire control which are common to most rangekeepers, directors, and stable elements. For that reason the Mark 34 Director, the Mark 8 Rangekeeper, and the Mark 41 Stable Vertical have been used to explain the various components used and their functions, and the problems to be solved and their solutions in assuring that the guns are correctly positioned to hit the target—which is the goal of every action of the Fire Control Technician.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Training Publications Section of the Bureau of Naval Personnel and of those activities of the naval establishment especially cognizant of the technical aspects of fire control. Special credit is given to the Fire Control Technician School, Class B, Washington, D. C., and the Bureau of Ordnance for assisting in the technical review of the text.

STUDY GUIDE

The table below indicates which chapters of this book apply to your rating. To use the table, follow these rules:

1. Select the column which applies to your rating. If you are advancing in the General Service Rating, you will use the column headed "FT." If you are advancing in one of the Emergency Service Ratings, you will use the column headed by your particular rating—FTA, FTM, FTU, or FTG.
2. Observe which chapters have been marked in your rating column. The 2 indicates the rate level to which you are advancing.
3. Study those particular chapters. They include information which will assist you in meeting the qualifications for your rating. (See appendix III of this book for a complete list of qualifications for advancement in rating.) In order to gain a well-rounded view of the duties of the General Service Rating, it is recommended that you read the other chapters of this book even though they do not pertain directly to your rating.
4. Here is an example: If you are advancing in the Emergency Service Rating to Fire Control Technician U (Underwater) 2, you will select the column headed FTU. Following this column down you will observe that you must study chapters 1, 2, 3, 4, 5, and 11.

Chapter	FT	FTA	FTM	FTU	FTG
1	2	2	2	2	2
2	2	2	2	2	2
3	2	2	2	2	2
4	2	2	2	2	2
5	2	2	2	2	2
6	2	2	--------	--------	2
7	2	2	--------	--------	2
8	2	2	--------	--------	2
9	2	2	2	--------	2
10	2	2	2	--------	2
11	2	2	2	2	2
12	2	2	--------	--------	2
13	2	2	2	--------	2
14	2	2	--------	--------	2
15	2	2	--------	--------	--------
16	2	2	2	--------	2

READING LIST

NAVY TRAINING COURSES

Fire Control Technician 3, NavPers 10173
Basic Electricity, NavPers 10086
Basic Electronics, NavPers 10087
Fire Control Radar Fundamentals, NavPers 91901
Electronics Technician 2, Vol. 2, NavPers 10191

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Correspondence

Number	**Title**
CA 781	*Elementary Electricity*

Self-Teaching

MA 781	*Elementary Electricity*
MA 784	*Electric Wiring*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

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FIRE CONTROL TECHNICIAN 2

CHAPTER 1

HOW TO ADVANCE

In your fire-control career thus far, you have been assisting a senior Fire Control Technician in the testing, disassembly and assembly of equipment, and performing routine operational adjustments in the upkeep of the fire-control equipment on board. The insignia on your arm points out that you are a technical man.

As an FT3 you performed two types of duties: first, your military duties, and second, the duties of a specialist in your technical rate. These two types of duties will continue throughout your naval career.

This text does not cover your military duties; that is done in the *General Training Course for Petty Officers*, NavPers 10055. However, as a Petty Officer, one thing that you must remember is that you have become a leader of men, not only in military duties, but also in the performance of your technical duties. How well you accomplish your duties and lead your men will determine, to a large extent, how far you advance. As you are now ready to prepare for further advancement in your technical rate, this text has been prepared to assist you in that phase of your work.

GENERAL QUALIFICATIONS

Qualifications for Fire Control Technicians are issued periodically by the Bureau of Personnel and may vary in detail from time to time. Summed up, the qualifications now required for an FT2 are described here:

As a Fire Control Technician 2 you should have a general knowledge of the following: basic mechanisms, basic synchros, basic electricity, basic electronics, and gyro principles. You should have a general knowledge of all the fire-control equipment on board—what it does, how it does it, and what must be done to keep it operating.

You should be able to read a blueprint, and to locate switches and junction boxes pertaining to any fire-control circuit. You should have a complete knowledge of the piece of equipment to which you are assigned. You must know its relationship to other equipment, such as, for example, the relationship of director to computer or computer to gun—and you must be able to keep it operating smoothly and efficiently.

The detailed qualifications you must demonstrate and know are listed in appendix III.

CONTENTS OF TEXT

This text is organized to help you acquire the above-named knowledge and skills as easily as possible. It begins with simple electrical and mechanical computing mechanisms and amplidyne circuits which you will eventually encounter. With your knowledge of basic mechanisms, electricity and electronics, acquired from the basic Navy Training Courses and the FT3 book, you should understand these mechanisms easily.

In this course you will also learn of the effect of wind, gravity, and air resistance on a projectile in flight. The relative motion between the firing ship and the target in relation to the problem will be explained. The effects of roll and pitch and the resulting corrections to the problem will be covered and, finally, the transmission of the problem solution to the gun to enable you to hit your target will be included.

You may think this is all, but it isn't. Your computing mechanisms may be solving your fire-control problem correctly, but what good is a correct solution if your battery is not aligned properly. So you must know how to align your battery so that the guns will point in the proper direction to hit the target. Here again your knowledge of basic synchros comes in handy.

If you are a bit rusty on your basic subjects, have the basic texts on hand so that you may refer to them. Such Navy Training Courses are: *Mathematics*, Volume 2, NavPers

10070–A, *Blueprint Reading and Sketching*, NavPers 10077-A, *Basic Electricity*, NavPers 10086, and *Basic Electronics*, NavPers 10087. These texts will prove invaluable.

USING ORDNANCE PUBLICATIONS

When you complete this course, do not think that you can maintain the fire-control equipment on board without any futher help, even though your knowledge is greatly improved. Additional help will come from various publications distributed by the Bureau of Ordnance such as *Ordnance Data*, or "OD's," and *Ordnance Pamphlets* or "OP's," and from practical on-the-job experience from day to day.

The BuOrd publications will pertain to an individual piece of equipment according to its Mark and Mod and will give you details of the equipment that cannot be covered in this text. Learn to use these "OD's" and "OP's" properly. They are absolutely essential to your learning the proper operation and maintenance of the specific gear for which they are prepared. Some typical publications you will use are:

OP 1060	*Gun Director Mark 37*
OP 1063	*Stable Element Mark 6*
OP 1064	*Computer Mark 1A*
OP 1068	*Rangekeeper Mark 8*
OP 1140	*Basic Fire-Control Mechanisms*
OP 1303	*U. S. Navy Synchros*

Now let's look at some of the types of billets you may expect to fill when you qualify as an FT2, and what you will actually DO on those billets. You will really learn your job and prove you are qualified as you learn to apply your knowledge and acquire your skills through actual on-the-job performance.

On a battleship or cruiser you may be assigned to one or more directors Mark 37, or to either of the main or secondary plotting rooms, or you may have a complete fire-control system, that is, a director Mark 37, secondary plotting room and the 5″ battery. When assigned to any of the aforementioned billets, you will also be assigned a complement of men—usually Seaman and FT3's.

The maintenance, operation, and cleanliness of these directors and plotting rooms, or of the fire-control system will be your responsibility. Instructing the men assigned to you will also be part of your job. With proper instruction from you, these men will help you carry out your responsibilities and also assist you in advancing further up the ladder. Always remember that one of these men will have to fill your shoes as you advance in rating.

Though the billet to which you are assigned is primarily your responsibility, you can always call on your first class or chief, who will help you should any difficulty arise in carrying out your technical duties. This may not be true on all ships. For example, you may be assigned to a destroyer and find yourself the leading technician on board. There may be no first class or chief to help you there. If so, you will have to maintain all of the fire-control systems on board with the help of seamen and third class technicians. This may sound like a big job for one technician to do, but you can do it if you learn your job well and instruct your lower-rated men properly.

With careful study of this text and the reference texts mentioned, and with conscientious application of the knowledge gained by practical on-the-job performance, you should be able to qualify as an FT2 capable of filling a very important billet on any type of fighting ship in the Navy.

HOW TO STUDY THIS TEXT

Read the preface. It contains a statement of the purpose of this training course. Look at the chapter titles. From them you will get a general idea of the contents of the book. Then look through the book and get acquainted with its general organization. Special attention should be given to the illustrations. They give a lot of information in a small amount of space. As you read, make your own drawings and sketches, as needed, to help you understand the equipment you are studying.

Finally, work the quiz at the end of each chapter and check your answers with the correct ones in an appendix at the back of the book. This is a good way of finding out what sections you need to restudy. Discussions of difficult points in the textbook with your mates are helpful and are encouraged. Your leading petty officer or division officer will also help you over the rough spots. Be thorough in your study—then, when you are ready for the quizzes, make your own choices of the answers. Only by making sure that you understand the principles and solutions described in this course will you be getting from the course the help you need in preparing for the advancement examination.

QUIZ

True and False

1. How well you accomplish your duties and lead your men will determine, to a large extent, how far you advance.
2. A general knowledge of basic subjects is not helpful to a fire-control technician.
3. Knowledge of blueprint reading will not help a fire-control technician in maintaining the equipment.
4. Battery alignment is not necessary, if the computing mechanism solves the fire-control problem correctly.
5. The BuOrd publications pertain to individual pieces of equipment according to its Mark and Mod.
6. In disassembling and assembling equipment, the technician should consult the publication for that piece of equipment.
7. The maintenance, operation, and cleanliness of a director, plotting room, or of a fire-control system will never be your responsibility.
8. Instructing the men assigned to you will also be part of your job.
9. As a Fire-Control Technician 2, you will always have a first class or chief to go to for assistance.
10. Making your own drawings and sketches will not help in understanding this textbook.

CHAPTER 2

COMPUTING POTENTIOMETERS

The fire-control problem can be solved by electronics or mechanics, or by a combination of both as in an electromechanical computer. The computing units of a mechanical computer are made up of cams, gears, differentials, integrators, multipliers, and similar mechanical parts. In an electrical computer you use transformer resolvers and computing potentiometers, but both types of computers use synchros to transmit gun orders.

This chapter will explain how computing potentiometers multiply and divide. These potentiometers are made with extreme accuracy. They are wire-wound with very fine-resistance wire, and the contact arm has a very narrow contacting area to increase the smoothness of control.

The two general types of computing potentiometers are LINEAR and TAPERED (or shaped). In the linear unit the total resistance of the potentiometer is distributed equally around its form, while the tapered unit has its total resistance distributed unequally around the form.

THE LINEAR POTENTIOMETER

Figures 2–1 and 2–2A show the construction of a linear potentiometer. It has the same width and the same thickness throughout its length and every turn of wire has the same length, the same cross-sectional area.

Since every turn has the same length and cross-sectional area, every turn has the same resistance, or, in other words, the potentiometer resistance is EQUALLY distributed throughout the turns.

Now see what happens when a voltage is applied to a linear potentiometer. Refer to figure 2–2, which is a schematic of the linear potentiometer in figure 2–1. The voltage *e* is applied to the potentiometer between terminals *a* and *b* and is distributed EQUALLY across all of the turns because every turn has the same resistance.

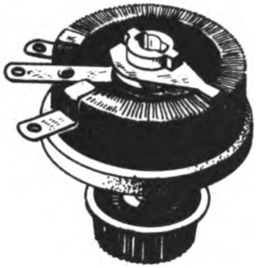


Figure 2–1.—Linear potentiometer.

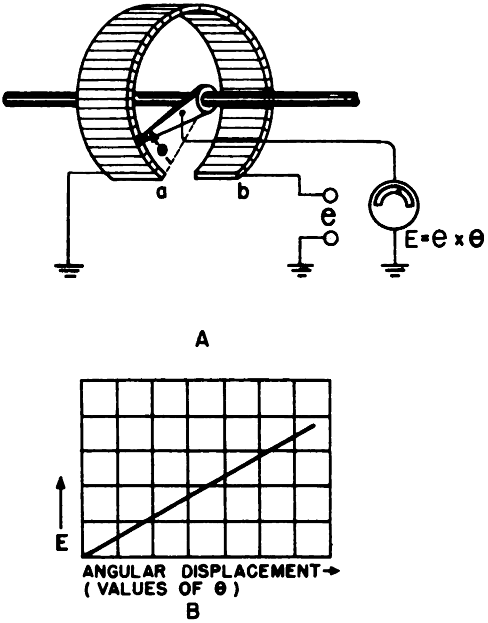


Figure 2–2.—Linear potentiometer voltage.

When the potentiometer arm is set at a certain point, a certain fractional part of the total turns is between the arm and the terminal. Since the voltage is distributed equally across each turn, there is the same fractional part of the total voltage between the arm and the terminal.

For example, say the arm is set so that one-half of the turns are between the arm and the terminal. The voltage E between the arm and terminal is—

$$E=e\times\tfrac{1}{2}, \text{ or, } E=\frac{e}{2},$$

where e is total applied voltage. Or suppose the arm is set so that one-fourth of the turns are between the arm and the terminal, then E becomes—

$$E=e\times\tfrac{1}{4}, \text{ or, } E=\frac{e}{4}.$$

You can figure the voltage between the potentiometer arm and the terminal by the fraction of the total turns between the arm and the terminal; but it is not practical to count turns. It is more practical to measure the angle through which the arm is turned and use this angle to measure the voltage between the arm and the terminal.

Let the symbol θ indicate the actual number of degrees rotation of the potentiometer shaft. Let k indicate the ratio between θ and the total number of degrees the potentiometer arm can be rotated. The voltage which appears at the potentiometer arm is then equal to the total applied voltage multiplied by the ratio k. With this method it is possible to determine the output voltage of the system without reference to the actual number of turns on the potentiometer, or, $E=e\times k$.

Use figure 2–2 as an example to see how this formula works. The arm in figure 2–2 can turn 300°, but in figure 2–2A the arm is turned only 30°. Therefore,

$$k=\frac{30^\circ}{300^\circ}=\frac{1}{10}$$

$\frac{1}{10}$ is then the fractional number of turns between the arm and the terminal. The voltage at the arm is therefore,

$$E=e\times k$$

$$E=e\times \tfrac{1}{10}.$$

If the arm is turned 150°

$$k=\frac{150^\circ}{300^\circ}=\frac{1}{2}$$

Then the voltage at the arm is calculated by:

$$E=e\times k$$

$$E=e\times \tfrac{1}{2}.$$

The graph in figure 2–2B plots the values of θ against the values of E. The result is a straight line which shows that E is directly proportional to θ. This type of potentiometer is called a linear POTENTIOMETER.

Now let us see how a linear potentiometer multiplies. Let the input voltage represent a distance in yards; then, as the potentiometer shaft is turned, the arm will multiply this distance by some fraction.

For example, let e (total applied voltage) represent 10,000 yards and turn the shaft so that the arm is positioned at three-fourths of its total distance. The output voltage E will be three-fourths of e, so E will represent three-fourths of 10,000, or 7,500 yards. Expressing this mathematically—

$$e=10{,}000 \text{ yards}$$
$$k=\tfrac{3}{4}$$
$$E=e\times k$$
$$E=10{,}000\times \tfrac{3}{4}=7{,}500 \text{ yards.}$$

The shaft position k is always a FRACTION LESS than ONE, and it is always some part of the total distance that the potentiometer arm can be rotated. This means that e is always being multiplied by a fraction and E is always some

FRACTIONAL PART of e. You can simplify this by considering e as UNITY or ONE. Then

$$E = 1 \times k,$$
$$\text{or } E = k.$$

In other words, E and k represent the same fraction, and the voltage E between the arm and terminal of the potentiometer reads the shaft position directly in a linear potentiometer.

HELICAL POTENTIOMETER

Figure 2–3 (A and B) show the construction of a helical potentiometer and you can see that the voltage E again changes in equal steps as the arm moves from turn and turn.

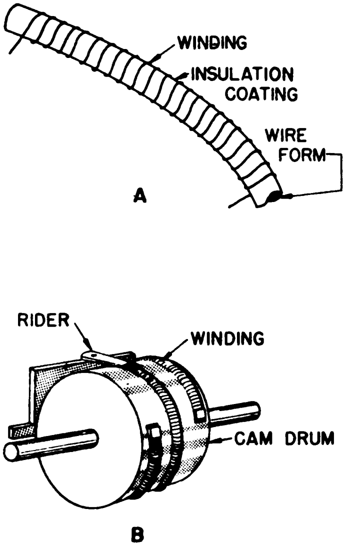


Figure 2–3.—Helical potentiometer.

The total number of turns on a linear potentiometer could be increased (and the potentiometer thus made more sensitive) by increasing the outside diameter of the potentiometer body, but the size would become quite large. This condition is eliminated by winding the resistance wire on a circular core about one-eighth of an inch in diameter as shown in figure 2–3A, and then winding this core several times about a drum in a helical fashion as shown in figure 2–3B. The resultant helical potentiometer then requires several turns of the shaft to contact the entire length of resistance.

SHAPED POTENTIOMETER

Shaped potentiometers are wound on specially shaped forms with each turn having different length, because the width and thickness of the form changes. This means that each turn has a different resistance which is thereby unequally distributed through the length of the potentiometer.

A shaped potentiometer is shown in figure 2–4A. As the arm moves, the voltage at the arm increases in UNEQUAL

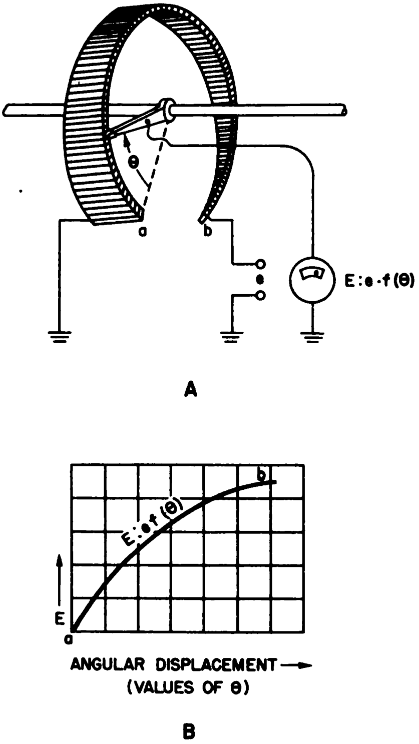


Figure 2–4.—Shaped potentiometer.

steps. In the example each voltage step is smaller and smaller in going from a to b because the shape of the potentiometer puts less and less resistance in each step.

The graph in figure 2–4B shows you the effect of these unequal steps. Notice that E is not directly proportional to θ. Instead, E is proportional to some function f of θ. Mathematically—

$$E=e\times f(\theta)$$

or, if e is considered as unity,

$$E=f(\theta)$$

Calibration of such a potentiometer must involve a consideration of $f(\theta)$, which is determined by how the potentiometer is wound. If it is wound to produce a trigonometric function, the calibration must be such that θ passes from 0 to 90 when the arm is rotated from a to b (see figure). The exact function depends on how the form is shaped. For example, the form may be shaped to produce a COSINE, in which case

$$E=e\times\cos\theta.$$

Or it may be shaped to produce a SINE, then

$$E=e\times\sin\theta.$$

The shaped potentiometers multiply a shaft position by a function of the angle through which their shafts are turned.

Taking another example, say that the potentiometer in figure 2–4 is shaped to produce the COSINE, and e represents a distance d. Now the potentiometer will multiply the distance by the cosine of the shaft position or, $E=d\times\cos\theta$.

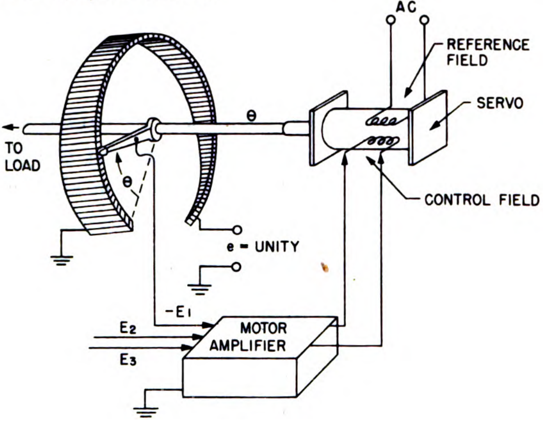
SIMPLE SERVO CIRCUIT

Figure 2–5 shows how a shaped potentiometer can be used in a simple servo circuit. Voltages $E2$ and $E3$ are outputs from other computing units. These two voltages are summed up by a resistance network at the amplifier input. Angle θ is the unknown—that is, the servo system solves for θ.

The shaped potentiometer multiples the input voltage e by a function of θ. The input voltage e is selected so that $E1$ equals the sum of $E2$ and $E3$ at solution, but e is phased so that $E1$ is opposite to $E2$ and $E3$. Then at solution—

$$E2+E3-E1=\theta.$$

At solution, θ is correct because $E2+E3-E1$ equals ZERO and the amplifier input is zero. The servo is stationary, and θ, the unknown, is solved.



$-E_1 = f(\theta)$

AND $-E_1 = E_2 + E_3$

$\therefore E_2 + E_3 - E_1 = 0$

Figure 2–5.—Simple servo system.

When the circuit is not in solution, θ is not correct, and $E2+E3-E1$ is not equal zero and the amplifier has an input of one phase or the other. This input is an error signal representing the incorrectness of θ. This error signal then drives the servo which repositions the potentiometer arm to the correct value of θ. At the correct value of θ, $E1$ equals $E2+E3$, and nulls the signal.

SHUNTED POTENTIOMETERS

Another way of shaping a computing potentiometer is shown in figure 2–6. The shaping is done by connecting different shunting resistors across every few turns. The

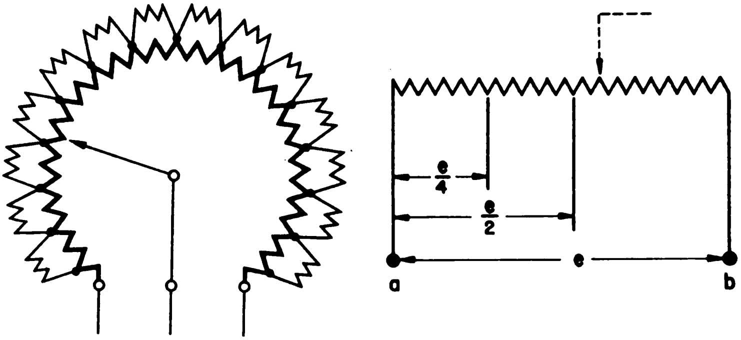


Figure 2-6.—Shunting resistors.

amount of resistance at any given set of turns is adjusted by the size of the shunt. Thus, by adjusting the size of the shunting resistors, the potentiometer can be shaped to any function of the shaft angle.

RECIPROCAL CIRCUIT

Figure 2–7 shows a reciprocal circuit of a computing potentiometer. The voltage *A* is the input to the circuit and is connected across the linear "pot," as the potentiometer is usually called. The shaft position *θ* is the output.

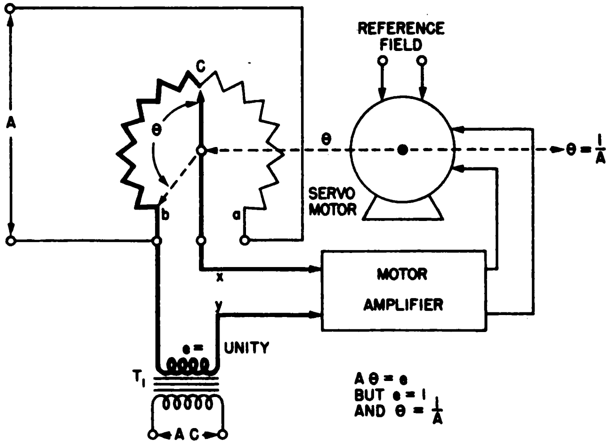


Figure 2-7.—Reciprocal circuit.

For example, say that A represents a certain number of yards, then θ represents the reciprocal of A $\left(\frac{1}{A}\right)$ number of yards in such a circuit.

The operation of the reciprocal circuit is as follows: the voltage between the "pot" arm and the terminal is equal to $A\theta$. This voltage is matched against e, the unity voltage at $T1$. If $A\theta$ and e are equal, there is no input to the motor amplifier. Then θ is the reciprocal of A, because

$$A\times\theta=e$$
$$A\times\theta=1$$
$$\theta=\frac{1}{A}.$$

Say that $A\theta$ is NOT equal to e. This puts a voltage across points x and y and the motor amplifier gets an error signal which then drives the servo motor to position the arm of the "pot" until $A\theta$ is equal to e. The servo stops driving when $A\theta$ is equal to e because the signal is nulled. Then

$$\theta=\frac{1}{A}.$$

Now substitute numbers to see how the reciprocal circuit works. Say that the input A represents 1, and the A and e voltages are the same. The servo will drive the "pot" arm the full 360° and θ will equal 1, because

$$\theta=\frac{1}{A}$$

$$1=\frac{1}{1}.$$

Take another example. Say that the input A represents 2. This makes the A voltage twice as large as the e voltage and the servo drives the "pot" arm to point c in figure 2–7 where $A\theta$ is equal to e. Then $A\theta$ is equal to e when the "pot" arm is driven 180°, so

$$\theta=\frac{180^\circ}{360^\circ}=\frac{1}{2}.$$

Notice that θ is the RECIPROCAL of the input A.

MULTIPLICATION CIRCUIT

The circuit of figure 2–8 uses three linear "pots" to multiply shaft position A by shaft position B so that the product appears as shaft position C. Mathematically, the circuit solves this equation:

$$A \times B = C.$$

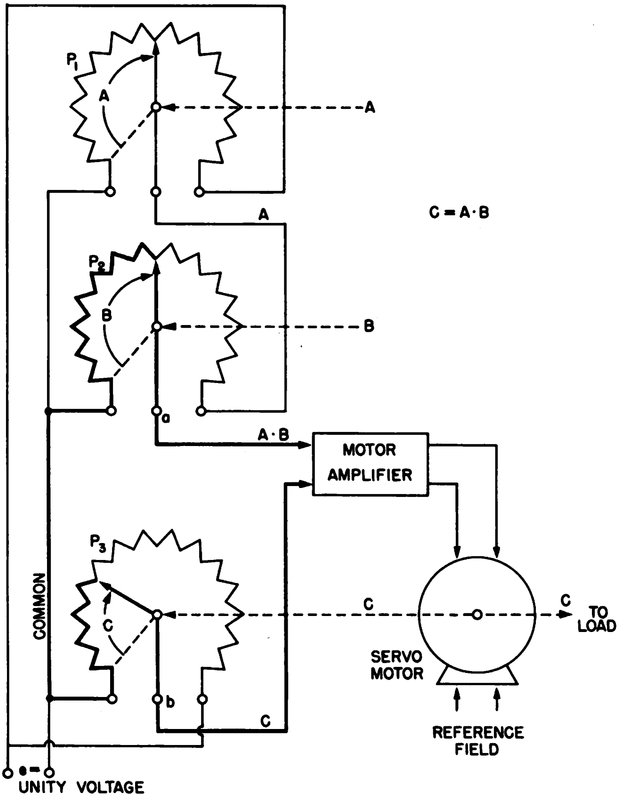


Figure 2–8.—Multiplication circuit.

The A shaft turns the $P1$ arm and the voltage at the $P1$ arm represents the position of the A shaft. This A voltage is then APPLIED to $P2$.

The *B* shaft turns the *P*2 arm. The output voltage of *P*2 represents the *A* voltage multiplied by the *B* shaft position. This *AB* voltage is matched against the *C* voltage from *P*3 and is shown as the heavily lined circuit in figure 2–8.

The *AB* and the *C* voltages determine the potentials at points *a* and *b*, and if the *AB* voltage equals the *C* voltage, there is no input to the motor amplifier.

When the *AB* and the *C* voltages are not equal, the potential difference between points *a* and *b* becomes an error signal to the motor amplifier to drive the servo, positioning shaft *C* until this signal is nulled.

A straight-line schematic of the multiplication circuit is shown in figure 2–9. Let us use this schematic to solve an actual problem.

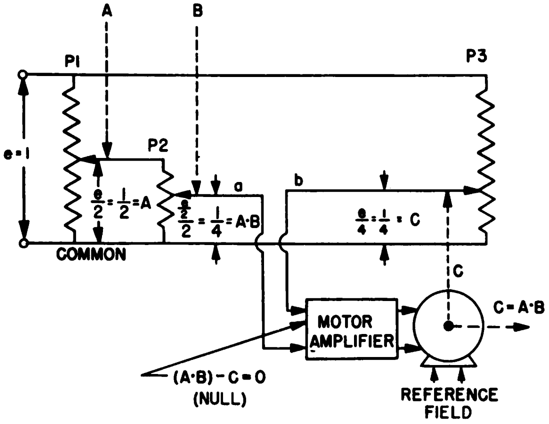

A
B
PI
P3
P2
e=1
$\frac{e}{2}=\frac{1}{2}=A$
a
b
$\frac{\frac{e}{2}}{2}=\frac{1}{4}=A\cdot B$
$\frac{e}{4}=\frac{1}{4}=C$
COMMON
C
C=A·B
MOTOR AMPLIFIER
(A·B)-C=0
(NULL)
REFERENCE FIELD

Figure 2–9.—Multiplictaion schematic.

Say that shaft position *A* equals ½ and shaft position *B* equals ½; then shaft *C* must be driven until it equals ¼ because—

$$C = A \times B$$

$$C = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}.$$

Shaft *A* turns the *P*1 arm ½ of its total angle and the *A* voltage is then

$$A = e \times \frac{1}{2} = \frac{e}{2}.$$

This A voltage is applied to $P2$ and the arm of $P2$ is turned ½ of its total angle by shaft B. Then the AB voltage is—

$$A \times B = \frac{e}{2} \times \frac{1}{2} = \frac{e}{4}.$$

The AB voltage $\frac{e}{4}$ represents shaft position A times shaft position B which is the potential at point a.

The potential at point b is the C voltage and the servo drives shaft C until the potentials at points a and b are equal. Points a and b are EQUAL ONLY WHEN VOLTAGE AB EQUALS VOLTAGE C. Therefore, voltage C is $\frac{e}{4}$ when the $P3$ arm is turned ¼ of its total angle.

DIVISION CIRCUIT

A simple division circuit is shown in figure 2–10 where the shaft position X is divided by shaft position Y to obtain the amplifier output Z. Mathematically, the circuit solves this equation:

$$Z = \frac{X}{Y}.$$

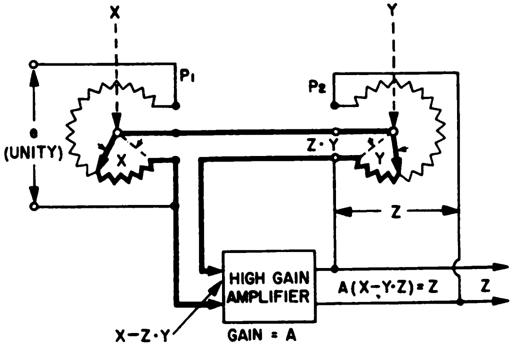


Figure 2–10.—Division circuit.

The following is an explanation of the division circuit. First, the linear "pot" $P1$ is supplied with the unity voltage e and the $P1$ arm is turned through the angle X; thus, the voltage output of $P1$ represents the quantity X.

Next, the linear "pot" $P2$ is supplied with the amplifier output voltage Z and the $P2$ arm is turned through the angle Y. The voltage output of $P2$ represents $Z \times Y$.

The two voltages representing X and ZY are matched against each other in the heavy-lined circuit of figure 2–10. This makes the amplifier input equal to $X-ZY$. The amplifier then increases this input by the gain A to make the amplifier output $Z=A(X-YZ)$.

Rearranging this equation, we have

$$\frac{Z}{A}=A(X-YZ).$$

$\frac{Z}{A}$ is small, and the higher the gain becomes, the smaller $\frac{Z}{A}$ becomes—so it approaches zero as the gain increases. We may say, therefore, that for very high values of gain, $\frac{Z}{A}$ is nearly equal to zero, so the equation becomes

$$\frac{Z}{A}=0=X-YZ.$$

Now we can solve for Z,
Since

$$0=X-YZ$$

$$YZ=X$$

$$Z=\frac{X}{Y}$$

Therefore, the output voltage Z represents shaft position X divided by shaft position Y.

An important thing to remember is that the higher the gain of the amplifier, the closer $\frac{Z}{A}$ is to zero and the less the error will be.

TRIGONOMETRY PROBLEMS AND CIRCUIT

Figure 2–11 shows a triangle in which the two sides X and Y are assumed to be known but the angle D is unknown.

The problem is to solve for the angle D with a given set of values of X and Y.

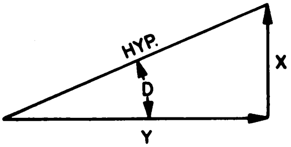


Figure 2–11.—Trigonometry problem.

To solve for D, trigonometry and the two known quantities X and Y are used to set up two terms of an equation involving D as follows:

$$\text{hypotenuse}=\frac{Y}{\cos D}$$

and,

$$\text{hypotenuse}=\frac{X}{\sin D}$$

or,

$$\frac{Y}{\cos D}=\frac{X}{\sin D}.$$

Simplifying this equation further—$Y \sin D=X \cos D$. This equation now states that for any given values of X and Y, there is only one angle (D) that will make $Y \sin D$ equal to $X \cos D$.

The circuit in figure 2–12 used this trigonometric equation to solve for D.

$P1$ is shaped to the sine function and is fed the input voltage Y. $P2$ is shaped to the cosine function and is fed the input voltage X. Therefore the output of $P1$ is Y times the SINE of the "pot" arm angle, and the output of $P2$ is X times the COSINE of the arm angle.

The $P1$ and $P2$ output voltages are matched in the heavy-lined circuit of figure 2–12 with the difference in the two outputs becoming the error signal to the motor amplifier, which will cause the servo motor to drive the arms of both "pots" until the error signal is nulled. Since the sine increases as the cosine decreases, the two outputs will not be equal until the arms are driven to angle D, because $Y \sin D= X \cos D$.

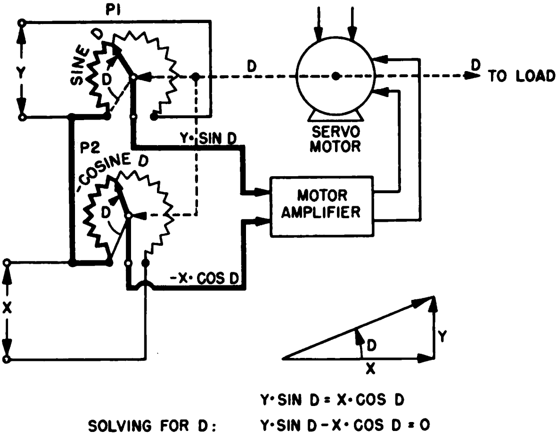


Figure 2-12.—Trigonometry circuit.

When both "pot" arms are at angle *D*, the output of angle *D* is fed to the load and the servo stops driving. If there is any change in *X* and *Y*, it will cause a corresponding change in angle *D* and the new values of *X* and *Y* furnishes an error signal that will cause the servo to drive the "pot" arms to the new value of angle *D*.

INTEGRATION

Potentiometers are also used in circuits to integrate angular and linear rates with respect to time. That is, their circuits continuously multiply the rate by the time that rate persists and then ADD all the product increments of rate multiplied by time.

For example, consider the job done by an integrator circuit when a bearing rate is constant. Say that the input shaft to the integrator represents a constant bearing rate of 5° per second. This input determines the speed of the output shaft, or a 5° input gives you a 5° output per second. But after a time interval of 60 seconds, the output shaft will have moved 5° times 60 seconds or 300°. Thus, after any length of time the distance the output shaft has turned represents the continuous addition of the product of RATE multiplied by TIME.

Now see what happens when the bearing rate is NOT CONSTANT, but is increasing. As the rate increases, the speed of the output shaft increases and at any instant the SPEED represents the rate AT THAT INSTANT. And the distance the shaft turns in any instant represents RATE multiplied by time FOR THAT INSTANT. Therefore, the TOTAL DISTANCE the shaft turns represents the SUM of all the instantaneous products of rate multiplied by time.

An integration circuit is shown in figure 2–13, where the mechanical input of *dB* positions the arm of the "pot" to multiply this input of *dB* with the unity voltage *e*. *dB* is now an output voltage instead of a shaft position.

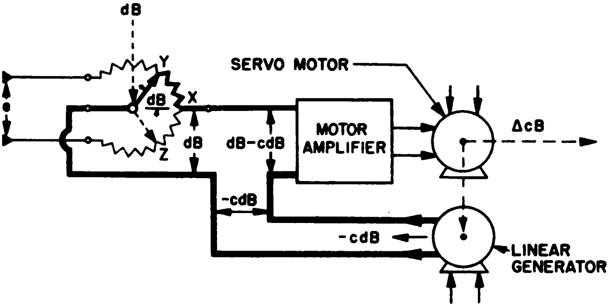


Figure 2–13.—Integrator Circuit, #1.

Notice the CENTER TAP at point *X* in figure 2–13 which splits *e* into two voltages of opposite polarity so that the POSITION of the *dB* shaft determines the polarity of the *dB* voltage. For example, let us say that *dB* is POSITIVE. The "pot" arm would then be at some point *Y* and the *dB* voltage would correspond to a POSITIVE *dB*. If the *dB* is NEGATIVE, the "pot" arm would be at some point *Z* and the voltage polarity would correspond to a NEGATIVE *dB*.

The *dB* voltage is amplified by the high-gain amplifier and then fed to the servo motor. The speed of the servo motor is directly proportional to the voltage at its terminals. The distance the servo shaft turns represents *dB* multiplied by time or Δ*cB*.

The LINEAR GENERATOR shown in figure 2–13 acts as a servo speed regulator so that ΔcB can follow any change in dB. The output of the linear generator is cdB which is directly proportional to the servo speed since the generator is driven by the servo motor. The generator is also phased so that cdB opposes dB.

To see how cdB is used, trace out the heavy lines in figure 2–13. You will see that the error signal input to the amplifier is $dB-cdB$, which continuously corrects the servo so that its speed always represents dB.

Take an example to see how the system works. Say that dB has a bearing rate of 5° and the dB voltage equals 1 volt. The linear generator produces $-cdB$ equal to 0.9999 volts. This means that the error signal, $dB-cdB$, is equal to 0.0001 volt.

Comparing the 0.0001-volt error signal to the 1 volt dB input, the error is only one part in ten thousand. This makes cB, equal to dB multiplied by time, accurate to one part in ten thousand.

To explain how $-cdB$ controls the servo speed, say that dB is increasing. Immediately $dB-cdB$ increases and the servo speeds up to correspond to the increased dB. The servo motor drives the linear generator and $-cdB$ increases to keep the servo speed constant. The opposite is true for a decreasing dB.

Summing it up, $-cdB$ produced by the linear generator does two things. First, it keeps the servo speed constant for constant values of dB and second, it adjusts the servo speed for any changes in dB or any changes in the servo load.

OTHER INTEGRATORS

Figure 2–14 shows another simplified integrator circuit. The input dB is a shaft position which is fed to a potentiometer that controls the frequency of the 30-90-cycle oscillator.

The dB frequency of the oscillator drives a synchronous motor $M1$, whose speed is directly proportional to the dB frequency.

The 60-cycle oscillator drives another synchronous motor $M2$, whose speed is constant because the 60-cycle frequency is constant.

*M*1 and *M*2 drive the two sides of a differential which makes the spider gear rotate at a speed proportional to the DIFFERENCE between the two motor speeds. The spider output is Δ*cB*.

For a zero *dB*, the 30-90-cycle oscillator produces a 60-cycle frequency. Then *M*1 rotates at the same speed as *M*2 and Δ*cB* equals zero.

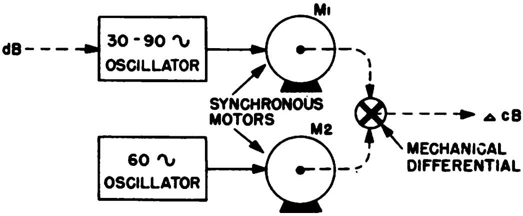


Figure 2-14.—Integrator circuit, #2.

Say that *dB* in this circuit is equal to −20°. This value of *dB* positions the "pot" arm so that the 30-90-cycle oscillator produces a 30-cycle frequency. Since the speed of *M*1 is directly proportional to 30 cycles, the speeds of *M*1 and *M*2 are not EQUAL and the output of the spider gear will be −Δ*cB*.

If *dB* is equal to +20° per second, the 30-90-cycle oscillator would produce a 90-cycle frequency and the output of the spider would be a +Δ*cB*.

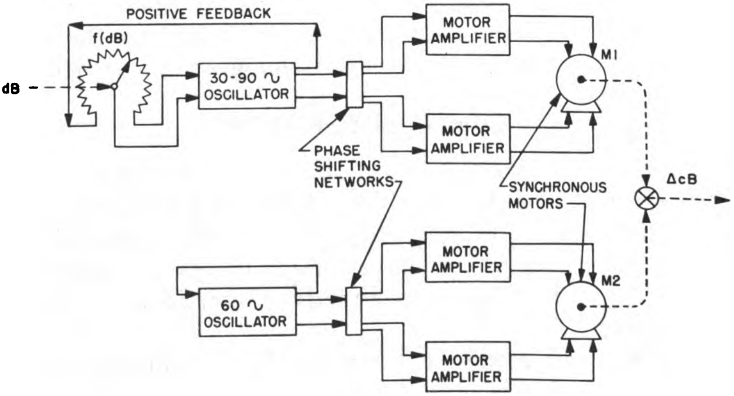


Figure 2-15.—Integrator details.

The details of an integrator circuit are shown in figure 2–15. The potentiometer is shaped to a function of *dB*. This function is necessary in order to make the frequency of the oscillator directly proportional to the bearing rate *dB*.

Next, see how the two synchronous motors are powered. Two phase-shifting networks split each oscillator output into two voltages that are 90° out of phase and feed their respective motor amplifiers. The voltages are then amplified and fed to the motors. The speed of each motor is determined by the frequency of the oscillator outputs.

POTENTIOMETERS IN PICK-OFF CIRCUITS

Potentiometers are used to null the signal in lead-angle gyro pick-off systems. Figure 2–16 shows a simplified pick-off circuit. This circuit is a good example of the pick-offs you will find in almost every GFCS.

First, trace out the heavy-lined circuit in figure 2–16 and

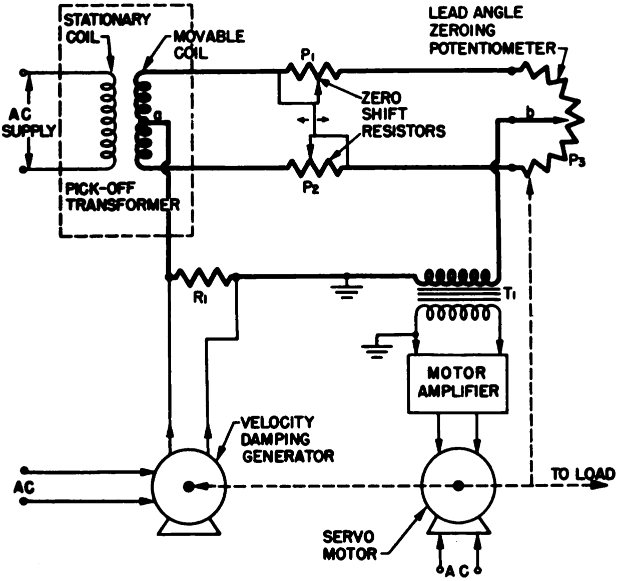


Figure 2–16.—Potentiometer, pick-off circuit.

see its similarity to a bridge circuit. The halves of the movable coil of the pick-off transformer form two sides of the bridge and the halves of the zeroing potentiometer form the other sides. The voltage between these two sides is across the primary of *T*1, and becomes the input to the amplifier.

Now to trace the signal. The signal is picked up by the movable coil in the pick-off transformer. For zero lead angle, the movable coil has equal voltages induced in its two halves. Point *a* and point *b* are at equal potential; hence, no signal.

But for a lead angle in one direction, the top half of the movable coil has the greater induced voltage. And for a lead angle in the opposite direction, the bottom half would have the greater induced voltage. In either case the bridge would be unbalanced and a potential difference would appear between point *a* and point *b*. This difference is fed across *T*1. The phase of this signal depends on which half of the movable coil has the greater voltage.

The signal from *T*1 is amplified and fed to the servo motor. The servo motor does two things: first, it turns out the lead angle to the load, and second, it drives the *P*3 arm in response to null the signal.

The velocity damping generator in figure 2–16 produces a negative feedback proportional to the speed of the servo. The feedback is across *R*1 where it combines with the signal to damp the system to increase its dynamic accuracy.

*P*1 and *P*2 in figure 2–16 are connected to operate as rheostats. *P*1 adjusts the resistance in the top right arm of the bridge, and *P*2 adjusts the resistance in the bottom right arm of the bridge.

Both *P*1 and *P*2 are on the same shaft and are adjusted simultaneously. When the resistance of *P*1 is increased, the resistance of *P*2 is decreased. Or if the resistance of *P*1 is decreased, the resistance of *P*2 is increased. Thus, by adjusting the shafts, the potentials at points *a* and *b* are adjusted. This adjustment is used to set the *P*3 zero position at the center of *P*3.

QUIZ

1. A shaped computing potentiometer always differs from a linear potentiometer in
   - a. physical shape
   - b. physical size
   - c. distribution of total resistance
   - d. size in terms of total resistance
2. The function of θ of a shaped potentiometer is determined by the
   - a. voltage across the potentiometer
   - b. shape of the form
   - c. cross-sectional shape of the wire
   - d. total resistance of the potentiometer
3. When shunting resistors are used to shape a potentiometer, the function is determined by the
   - a. power dissipated in the shunting resistors
   - b. voltage impressed across the potentiometer
   - c. resistance of the shunting resistors
   - d. current carried by the shunting resistors
4. In the multiplication circuit the voltage impressed across *P*2 is equal to the voltage that is
   - a. impressed across *P*1
   - b. impressed across *P*3
   - c. on the arm of *P*3
   - d. on the arm of *P*1
5. In the division circuit of figure 2–10, which potentiometer arm is positioned by a motor to null the error signal *Z*?
   - a. *P*1 only
   - b. *P*2 only
   - c. *P*1 and *P*2
   - d. Neither *P*1 or *P*2
6. In the trigonometry circuit, figure 2–11, if the value of *Y* increases relative to the value of *X*, which of the following will increase?
   - a. Angle *D*
   - b. Sine angle *D*
   - c. Cos angle *D*
   - d. None of the above
7. The sum of all the instantaneous products of rate multiplied by time is represented in the output of the integrator by the
   - a. total distance the shaft has turned
   - b. speed with which the shaft is turning
   - c. total time the shaft has been turning
   - d. maximum rate at which the shaft has turned

8. In the integrator circuit, figure 2–13, the polarity of the *dB* voltage input to the amplifier is determined by the
   a. speed of the servo motor
   b. speed of the linear generator
   c. size of the linear generator output
   d. position of the *dB* shaft
9. The error signal input to the amplifier in the integrator circuit, figure 2–13, is the difference between the actual servo speed and the correct servo speed because the linear generator output is
   a. phased to oppose the unity voltage
   b. phased to oppose the *dB* voltage
   c. equal to the unity voltage
   d. not proportional to the unity voltage
10. No signal appears across *T*1, figure 2–16, in the lead angle pick-off system when the
   a. bridge is balanced
   b. arm of *P*3 is centered
   c. voltage across *R*1 is at a maximum
   d. resistance of *P*1 equals that of *P*2
11. The bridge in the lead angle gyro pick-off system is balanced to null an error signal by
   a. feeding back a negative voltage across *R*1
   b. repositioning *P*1 and *P*2
   c. repositioning the movable coil
   d. repositioning the arm on *P*3

CHAPTER 3

TRANSFORMER RESOLVERS

Transformer resolvers operate like the computing potentiometer but are used in circuits which solve vector problems. In general, three kinds of vector problems can be solved. First, the resolver can separate a vector into its two right-angle components; this is called RESOLUTION. Second, the resolver can combine two right-angle components to produce the vector; this is called COMPOSITION. Third, resolvers can combine given vectors to produce a total vector which is the sum of the given vectors; this is called COMBINATION.

RESOLVER CONSTRUCTION

Figure 3–1 shows a cutaway of a transformer resolver showing the two major parts, the rotor and the stator. The rotor and stator cores are made of special metal laminations called Mu-metal which has a very high permeability and a low hysteresis loss.

The rotor windings are connected to one terminal strip and the stator windings are connected to the other terminal strip shown in figure 3–1.

The calibrating resistors shown in figure 3–1 are precision wire-wound resistors and serve two purposes. First, they compensate for voltage inaccuracies in the resolver windings and second, they aid in compensating for phase shifts introduced by load changes.

Rotor Windings

The rotor windings shown in figure 3–2 are two independent windings 90° apart. Winding number *1* consists of six

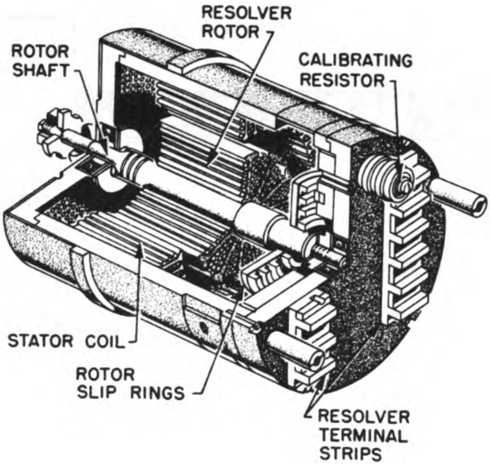


Figure 3-1.—Cutaway of transformer resolver.

coils wound parallel to each other, connected in series, and having a vertical axis. Winding *2* is also made up of six coils, but has a horizontal axis and is displaced 90° angularly from winding *1*. This 90° displacement prevents any magnetic coupling between the two windings.

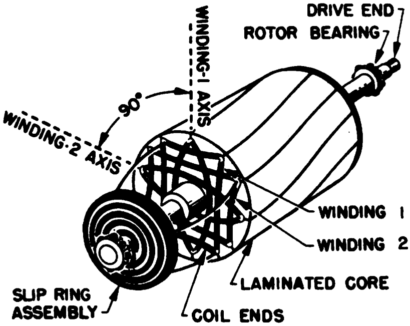


Figure 3-2.—Rotor windings.

The four slip rings are connected to the four leads from the rotor windings. Brushes conduct the current from the slip rings. The brushes are connected to terminals on the terminal strip labeled *R*1, *R*2, *R*3, and *R*4.

Stator Windings

The stator windings are wound in the same manner as the rotor windings. The four leads are connected to the remaining terminal strip and labeled *S*1, *S*2, *S*3, and *S*4.

Resolver Schematic

Figure 3–3 shows a resolver schematic with the stator and rotor windings 90° apart. The schematic in figure 3–3 is the one usually used in prints. However, many times one of the stator or rotor windings is inactive and will not be shown on the print.

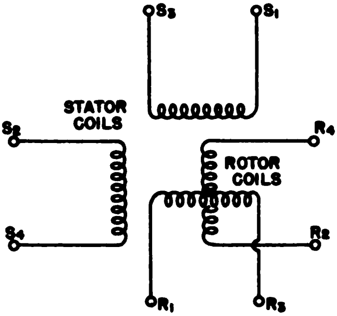


Figure 3–3.—Resolver schematic.

RESOLVER PRINCIPLE

The transformer resolver operates on the principle of a transformer. The two stator windings act as primaries and the two rotor windings act as secondaries. The rotor windings turn with the rotor shaft. Thus, the secondaries may be at any angle with respect to the primaries.

Figure 3–4 shows the rotor in three different positions with respect to the stator. Since similar things happen in both rotor windings, only one rotor winding is shown for simplicity of explanation.

In figure 3–4A the rotor and stator windings are lined up with each other, that is, the angle θ between the stator and rotor is 0°. With the rotor and stator in this position, ALL the flux through the stator winding cuts the rotor winding and the voltage induced in the rotor is maximum.

For example, say the turns ratio between the stator and the rotor in figure 3–4A is 1:1, and the input voltage Ei is 1 volt. Then the output voltage Eo is also 1 volt, ignoring the small transformer losses.

The formula to find Eo is—

$Eo = Ei \times \cos\theta$, where angle θ is the angle between the rotor and stator coils.

Then, when θ is 0°, the cosine of θ equals 1, and Eo is equal to $1 \times 1 = 1$ volt.

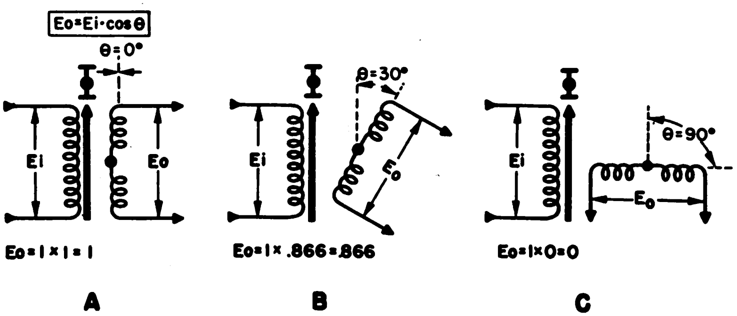


Figure 3–4.—Resolver principle, rotor and stator.

In figure 3–4B the rotor is turned so that the two windings are displaced by 30° and angle θ is equal to 30°. Now only a part of the stator flux cuts the rotor and the voltage induced in the rotor is computed:

$$Eo = Ei \times \cos 30°.$$

If the turns ratio is 1:1 and Ei is 1 volt,

$$Eo = 1 \times 0.866 = 0.866 \text{ v.}$$

If figure 3–4C the rotor is turned so that the two windings are displaced by 90°. With θ equal to 90°, the coupling between the stator and rotor is zero. The voltage induced in the rotor is zero, as can be seen by this calculation:

$$Eo = Ei \times \cos 90°$$

$$Eo = 1 \times 0 = 0 \text{ v.}$$

Now imagine that the rotor in figure 3–4 keeps on turning. The *Eo* again rises to a maximum at 180° and falls to zero at 270°. At 360° *Eo* is at a maximum again. In short, *Eo* follows the cosine function for the whole 360°. *Eo* also reverses phase at 90° and 270°; thus the phase of *Eo* corresponds to the positive and negative values of the cosine function in the four quadrants.

Summarizing; with the turns ratio of 1:1

Eo is proportional to the cosine of θ—

$$Eo = Ei \times \cos \theta$$

and, if *Ei* is a unity voltage, *Eo* is equal to the cosine of θ—

$$Eo = 1 \times \cos \theta$$

$$Eo = \cos \theta.$$

Two Rotor Windings

Now see what happens with both rotor windings in place as in figure 3–5. Say that winding *1* is the same winding considered in figure 3–4. Call it the COSINE winding, because the *Eo* of winding *1* is the cosine function.

Then, winding *2* is displaced by 90° from winding *1* and the voltage induced in winding *2* follows winding *1* by 90°. This means the voltage induced in winding *2* is proportional to the SINE FUNCTION, and winding *2* is called the SINE WINDING.

In figure 3–5A the cosine winding *1* is lined up with the stator winding. Angle θ is 0° and Eo_1 (output voltage for winding *1*) is

$$Eo_1 = Ei \times \cos \theta$$

$$Eo_1 = 1 \times 1 = 1 \text{ v}$$

but with θ equal to 0°, the sine winding *2* is at right angles to the stator winding and Eo_2 is

$$Eo_2 = Ei \times \text{sine } \theta$$

$$Eo_2 = 1 \times 0 = 0v.$$

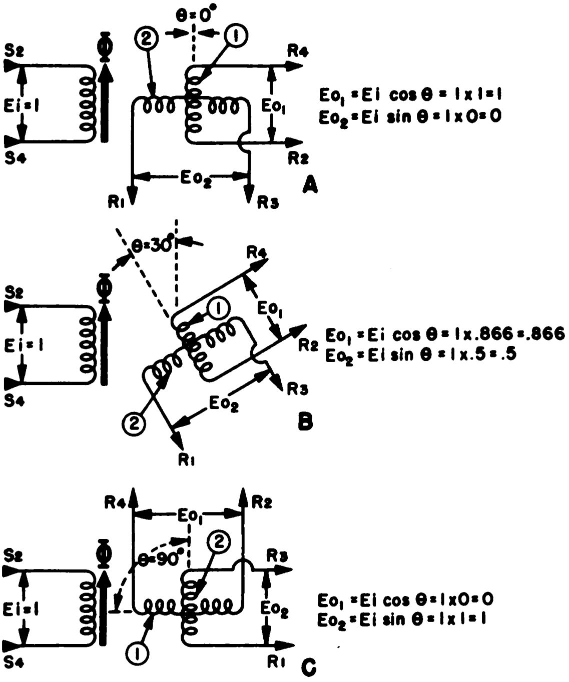


Figure 3-5.—Both rotor windings.

In figure 3-5B the rotor, both windings, has been turned counterclockwise 30°. The cosine winding now has an Eo_1 of

$$Eo_1 = Ei \times \cos 30°$$

$$Eo_1 = 1 \times 0.866 = 0.866 \text{ v}$$

but the sine winding has an Eo_2 of

$$Eo_2 = Ei \times \sin 30°$$

$$Eo_2 = 1 \times 0.5 = 0.5 \text{ v.}$$

All the equations as the rotor turns are shown in figure 3–5.

The important part of the transformer resolver principle to remember is that the induced voltage in one rotor winding is proportional to the COSINE function, and the induced voltage in the other rotor winding is proportional to the SINE function. When the input voltage Ei is unity

$$Eo_1 = \cos \theta$$

and

$$Eo_2 = \sin \theta.$$

Resolution

Resolution is the first vector problem which we'll solve with a transformer resolver. Figure 3–6 shows how a resolver separates a vector into its two components.

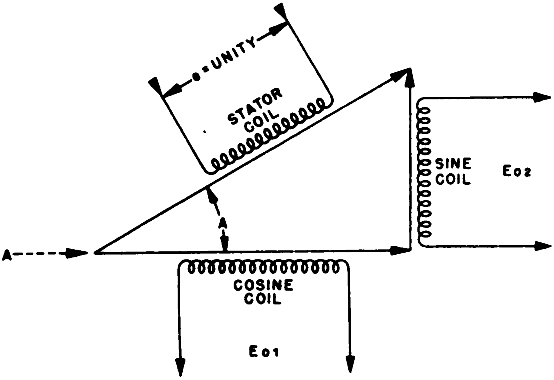


Figure 3–6.—Resolution, #1.

The hypotenuse of the triangle in figure 3–6 is the vector to be resolved. The side adjacent to angle A is the horizontal component, and the side opposite to angle A is the vertical component.

First, the stator coil of the resolver is energized with a unity voltage, Ei. This unity voltage represents the vector to be resolved. Next, the rotor of the resolver is turned through the angle A, and the induced voltage in the cosine coil represents the horizontal component because—

$$Eo_1 = 1 \times \cos A.$$

The induced voltage in the sine coil represents the vertical component because—

$$Eo_2 = 1 \times \sin A.$$

The two output voltages Eo_1 and Eo_2 solve the vector problem. Measuring Eo_1 gives you the horizontal component and measuring Eo_2 gives the vertical component.

Use the problem in figure 3–7 and resolve the vector R into its two components as another example. Vector R represents the distance 10,000 yards. R is at 30° to the horizontal.

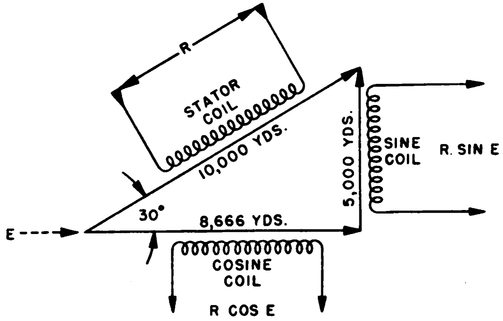


Figure 3–7.—Resolution, #2.

The stator coil of this resolver is energized with a unity voltage. In this case unity voltage represents R, 10,000 yards. When the rotor is turned 30°, the Eo_1 of the cosine coil is—

$$Eo_1 = 1 \times \cos 30°.$$

$$Eo_1 = 1 \times 0.866 = 0.866 \text{ v.}$$

Since unity voltage represents 10,000 yards, Eo_1 represents the horizontal component, or

$$0.866 \times 10{,}000 = 8{,}660 \text{ yards.}$$

The Eo_2 of the sine coil is—

$$Eo_2 = 1 \times \sin 30°$$

$$Eo_2 = 1 \times 0.500 = 0.500 \text{ v.}$$

and Eo_2 represents the vertical component, or

$$0.500 \times 10{,}000 = 5{,}000 \text{ yards.}$$

Figure 3–8 shows a more complicated problem in resolution. Three resolvers are connected in a circuit to solve this expression for angle C—

$$\sin A \times \sin B - \cos C.$$

A unity voltage is fed to the stator coil of the first resolver, Re_1, and the rotor of Re_1 is turned through the angle A. This makes the output of the sine coil of Re_1 equal to the sine of A. The sine of A is fed to the stator of Re_2 and, at the same time, the rotor of Re_2 is turned through angle B. This makes the output of the sine coil of Re_2 equal to—

$$\sin A \times \sin B.$$

The stator of Re_3 is also energized by a unity voltage and the rotor of Re_3 is turned through the angle C. This makes the output of the cosine coil of Re_3 equal to the cosine of C.

The outputs of Re_2 and Re_3 are phased to oppose each other in the heavy-lined loop of figure 3–8. This makes the input to the motor amplifier equal to—

$$\sin A \times \sin B - \cos C.$$

If we wish the input to the amplifier to be zero, we solve the equation:

$$\sin A \times \sin B - \cos C = 0$$

Then:

$$\sin A \times \sin B = \cos C.$$

If the input to the amplifier is not zero, the amplifier gets a signal and the servo drives to a new angle C and, at the same time, repositions the rotor of Re_3. The servo drives until the correct angle C is produced to make the amplifier input zero. When this correct angle is produced, the signal is nulled because—

$$\sin A \times \sin B = \cos C.$$

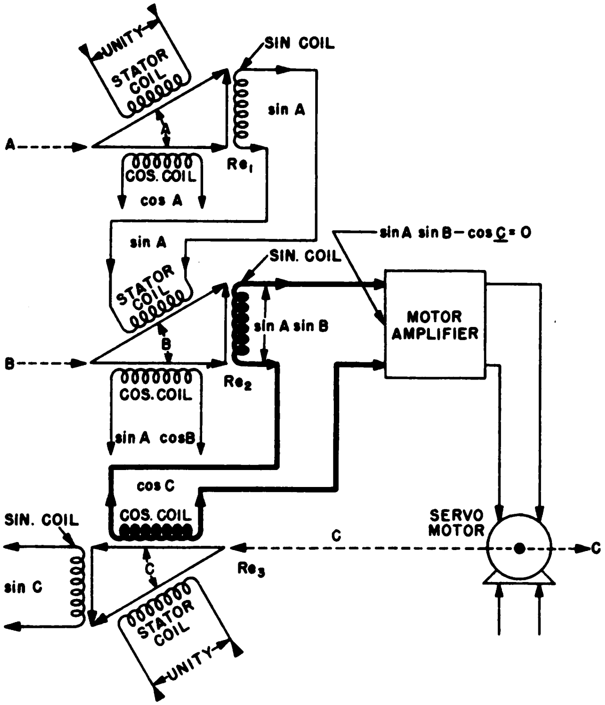


Figure 3–8.—Resolution, #3.

The servo drives to a new angle C whenever any change occurs in angles A or B. Thus, the system in figure 3–8 continuously solves the equation, $\sin A \times \sin B = \cos C$.

Composition

Combining the two components of a vector to produce that vector is known as composition. In other words, if the two sides of a right triangle are known and you solve for the hypotenuse, that is composition.

The resolvers use the same formula that you used in basic mathematics to solve right triangles—

$$a^2+b^2=c^2$$

or,

$$\sqrt{a^2+b^2}=c.$$

Now, use the problem in figure 3–9 as an example of composition. The two sides of the right triangle are known, with A sin θ and A cos θ representing the voltages of the two sides. The problem is to solve for the hypotenuse A.

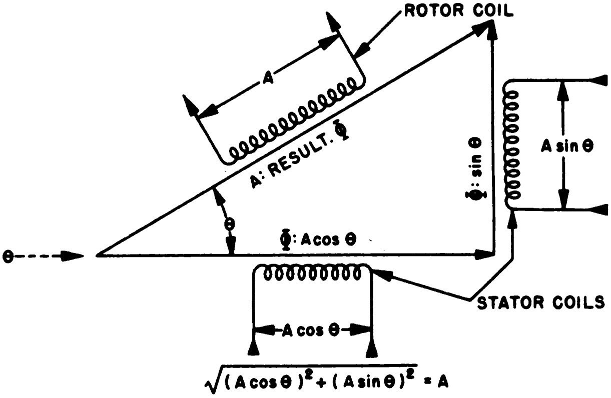


Figure 3–9.—Composition, #1.

The voltages A sin θ and A cos θ are fed to the two stator coils and each coil produces a flux field proportional to the strength of the voltage unit. These two flux fields are at right angles because the stator coils are at right angles in the resolver, and right angle flux fields combine according to this formula—

$$\Phi 1^2+\Phi 2^2=\Phi t^2$$

or,

$$\sqrt{\Phi 1^2+\Phi 2^2}=\Phi t.$$

where Φ1 is the field strength of stator coil *1*, and Φ2 is the field strength of stator coil *2*.

Notice that the resultant flux Φt is proportional to the square root of the sum of the squares of the two individual fields. Since the two fields are produced by the voltages $A \sin \theta$ and $A \cos \theta$, the resultant flux is proportional to—

$$\sqrt{(A \sin \theta)^2+(A \cos \theta)^2}.$$

The resolver rotor is turned through the angle θ so that the axis of the rotor coil comes into alignment with the axis of the resultant stator flux. The voltage induced in the rotor increases as the coupling increases and, at correspondence, the rotor voltage is proportional to the vector A where—

$$A=\sqrt{(A \sin \theta)^2+(A \cos \theta)^2}.$$

Voltage A is the hypotenuse of the right triangle in figure 3–9.

To see how the resolver continuously solves for A, refer to the servo circuit in figure 3–10.

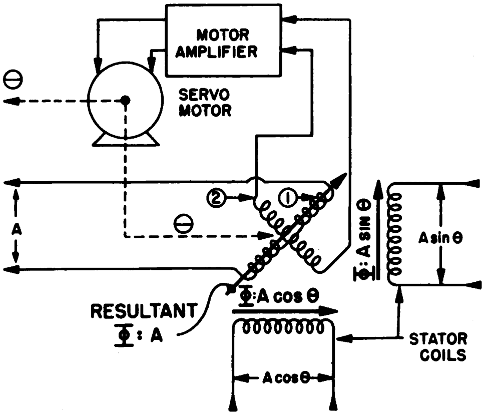


Figure 3–10.—Composition, #2.

The two voltages representing the two sides of the right triangle are again applied to the stator coils of the resolver, (fig. 3–10). The resultant flux induces a voltage in the rotor coil that is proportional to the hypotenuse A.

There is a second rotor coil, coil *2*, which supplies a signal to the motor amplifier to drive the servo. When coil *1* is cut by all the resultant flux, the output of coil *1* is proportional to A, but coil *2* is at right angles to that flux. Result—no voltage is induced in coil *1* and no signal goes to the amplifier. The servo does not drive because the circuit has solved the problem.

But when coil *1* is not cut by all flux, coil *2* feeds a signal to the amplifier and the servo drives out angle θ and drives the resolver in response. The servo continues to drive until coil *2* is at right angles to the flux and the signal is nulled. When the signal is nulled, coil *1* cuts all resultant flux and its voltage represents A. Also, when the signal is nulled, the servo shaft position represents angle θ.

If either input voltage changes, the resultant flux changes, and coil *2* feeds a signal to the amplifier so the servo will drive until the signal is again nulled. At this point the induced voltage in coil *1* represents the new value of A. Thus, the servo system in figure 3–10 continuously solves for A and θ.

Combination

Combination is a process of resolution and composition taking place simultaneously. Here is an example that will show you how combination works. Say that you have two angles A and B, and you want to produce these functions of the angles—

$$\sin A \cos B - \cos A \sin B$$

and

$$\sin A \sin B + \cos A \cos B.$$

Figure 3–11 shows the combination circuit that produces these two functions. The position of the Re_1 shaft is represented by angle A and the Re_2 shaft by angle B.

Coil *1* in the stator of Re_1 is energized by a unity voltage. Result—coil *2* in the rotor produces the sine of A and coil *3* produces the cosine of A.

The two outputs of Re_1, $\sin A$ and $\cos A$, are fed to the two stator coils of Re_2 which causes coil *4* to set up a flux proportional to $\sin A$, and coil *5* to set up a flux proportional to cos *A*. The resultant flux in *Re*₂ cuts the *Re*₂ rotor coils *6* and *7*. The induced voltages in coils *6* and *7*, however, depend on the rotor position, ANGLE *B*.

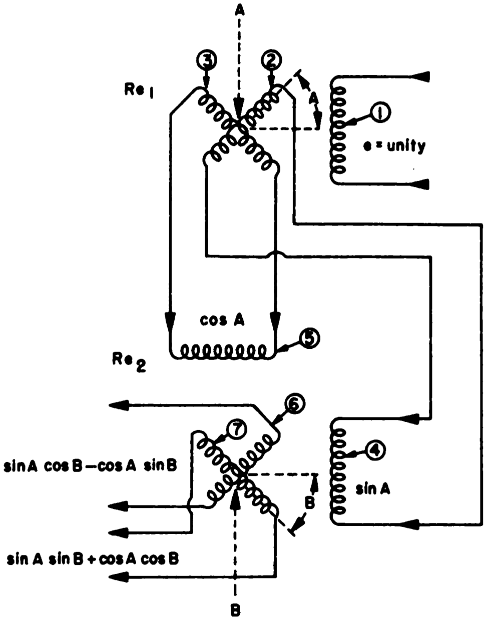


Figure 3–11.—Combination circuit.

To see exactly what happens in *Re*₂, look at the vectors in figure 3–12. The two heavy vectors are the flux fields set up by coils *4* and *5*. The vertical flux vector represents sin *A*, and the horizontal flux vector represents cos *A*.

Next locate the axis of the *Re*₂ rotor coils. Coil *6* is displaced from the sin *A* vector by angle *B*, and coil *7* is displaced from the cos *A* vector by angle *B*. Coil *6* has two flux components that are parallel to its axis, sin *A* cos *B* and −cos *A* sin *B*. These two flux components cut coil *6* and induce the coil *6* voltage, therefore, coil *6* voltage is proportional to —

$$\sin A \cos B - \cos A \sin \mathrm{B}.$$

Coil 7 also has two flux components that are parallel to its axis, cos A cos B and sin A sin B. These two flux components cut coil 7 and induce a voltage proportional to—

$$\cos A \cos B + \sin A \sin B.$$

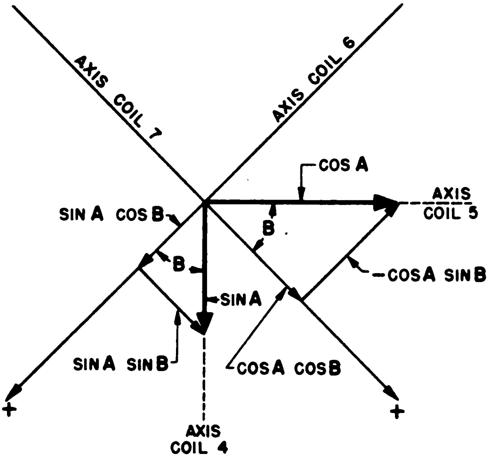


Figure 3–12.—Combination vectors.

Thus, the two rotor outputs of Re_2 are proportional to the two functions of A and B which were required.

Zeroing a Resolver

Before a resolver can solve any problems, it must be set on ELECTRICAL ZERO, that is, the rotor of the resolver must be set so that one rotor coil is at right angles to one stator coil, and the other rotor coil is at right angles to the other stator coil.

Trace out the heavy lines in figure 3–13. Two of these are the jumpers used to set a resolver on COARSE ZERO. The voltmeter is either a CRO or a VTVM.

A standard voltage E is connected across the terminals S_1 and S_3. This voltage E should never exceed 20 volts; always use the computer reference voltage when possible. If the reference voltage is not available, you can use a Variac to reduce the ship's supply to a proper value. Remember to use less than 20 volts or the voltage specified in the OP or OD.

Now loosen the flange mounting screws of the stator and, looking at the rear (brush end), turn the stator counterclockwise. Stop turning when the voltmeter reads the input E voltage. At this point you know the R_2, R_4 coil has no induced voltage because the voltmeter reads the E voltage alone, which means that R_2, R_4 is approximately at right angles to S_1, S_3, that is, R_2, R_4 is at coarse zero.

With the voltmeter reading the E voltage, turn the stator a little beyond coarse zero. The voltage at the voltmeter should INCREASE ABOVE E, because the voltage induced in the R_2, R_4 coils adds to E. Be sure the voltage at the voltmeter increases—this prevents zeroing at 180° out-of-phase.

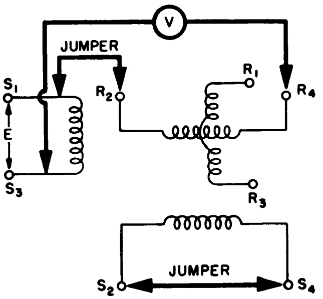


Figure 3-13.—Coarse zero.

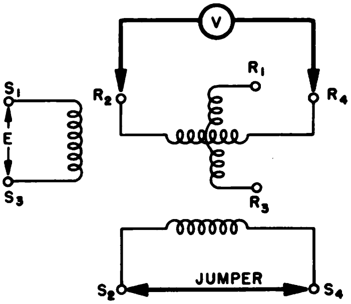


Figure 3-14.—Fine zero.

Now to set the resolver on fine zero. Figure 3-14 shows you how to re-connect the jumpers and voltmeter. Turn the stator in a direction so that the voltage on the voltmeter decreases and keep shifting the meter to the lower scales until the minimum voltage reading is obtained. The minimum voltage reading means that R_2, R_4 is exactly at right angles to S_1, S_3, that is, R_2, R_4 is at fine zero. Recheck this voltage after you secure the mounting screws.

RESOLVER TROUBLES

Resolvers are variable transformers and they draw varying currents. The varying currents are caused by different rotor positions. For example, when the rotor winding is parallel to the stator winding, the rotor is cut by all the stator flux. With the rotor parallel the rotor current is maximum and the stator winding is fully loaded, but when the rotor winding is not parallel to the stator winding, the rotor is not cut by all of the stator flux and some of the stator flux will leak. This makes the rotor current less than maximum and the stator winding is only partly loaded.

When one resolver is fed directly by another, the output resolver draws varying load currents from the input resolver which produces two bad effects. First, the varying load currents in the input resolver produce an internal voltage drop in the winding. This means varying, poor voltage regulation. Second, varying load currents produce a phase shift in the output resolver.

Voltage regulation is very important in a resolver because the resolver-voltage measures a particular function or quantity in the fire-control problem and, if the voltage regulation is poor, the resolver itself introduces inaccuracies into the problem.

Phase shift occurs because the leakage flux varies for different rotor positions. For example, when the axis of the stator winding is parallel to the axis of the rotor winding, there is little leakage flux between them.

The voltage and the current in the stator tend to be IN-PHASE. When the axis of the stator winding is out of alignment with a rotor winding, it is only partly loaded, and the stator leakage flux cuts across the stator itself. The stator winding then acts like an inductive reactance and the current tends to LAG the voltage by 90°. This means that the voltage of the output resolver is out-of-phase with the voltage of the input resolver.

Temperature is another cause for poor voltage regulation. When the temperature of the resolver winding changes, the resistance changes which varies both the potential difference across the resolver terminals and the phase shift in the windings.

To sum up the troubles that occur when two resolvers are directly connected, we have first, poor regulation due to varying currents and temperature changes and second, phase shift due to flux leakage and temperature changes.

To eliminate the voltage-regulation trouble, a booster amplifier is connected between the two resolvers. This booster amplifier uses voltage alone as its input. In other words, the booster draws practically no current from the input resolver, but the booster supplies power to the output resolver.

The booster amplifier is called a UNITY-GAIN power amplifier because it changes the voltage level very little, but it does furnish power to the output resolver.

The phase-shift trouble is cured by connecting a compensator network between the two resolvers. This network feeds back enough reactive voltage to cancel any shift in the output resolver. Thus, the compensator cancels phase shift so that the output phase is the same as the input phase.

To sum this up—the booster is necessary to maintain the resolver voltages at their correct values, and the compensator is necessary to maintain the resolver voltages in their correct phase.

QUIZ

1. Combining two right-angle components to produce the vector is called
    a. resolution
    b. integration
    c. combination
    d. composition
2. The two windings in the rotor of a resolver are displaced 90° from each other in order to
    a. compensate for voltage inaccuracies in the windings
    b. compensate for phase shifts introduced by load changes
    c. prevent coupling between the two windings
    d. prevent coupling between the rotor and the stator

3. The voltage induced in the sine winding of a resolver rotor is at a maximum when the angle θ is equal to
   a. 0°
   b. 30°
   c. 60°
   d. 90°

4. Across which coil is the unity voltage impressed when a vector is being resolved into two components with a transformer resolver?
   a. Stator
   b. Cosine
   c. Sine
   d. Tangent

5. If the voltage induced in the cos coil of Re_3 in figure 3–8 is greater than the voltage induced in the sine coil of Re_2, the servo motor turns in such a way as to
   a. increase angle A
   b. increase angle C
   c. decrease angle B
   d. decrease angle C

6. The input to the motor in figure 3–10 is zero when
   a. coil *2* is at right angles to the resultant force
   b. the voltage induced in coil *1* is zero
   c. the voltages induced in the rotor coils are equal
   d. the voltage induced in coil *2* is at a maximum

7. In figure 3–13 the rotor is set on coarse zero when the reading on the voltmeter is
   a. zero
   b. equal to the E voltage
   c. at a maximum
   d. at a minimum

8. Which of the following factors decreases as the angle between the rotor and stator of a resolver increases?
   a. Leakage flux
   b. Phase shift in the stator
   c. Rotor current
   d. Inductive reactance of the stator

9. In resolver circuits poor voltage regulation and phase shifts must be eliminated because of their effect on the
   a. ship's power supply
   b. rotor and stator windings
   c. accuracy of the resolver solutions
   d. windings of the follow-up motors

10. The voltage induced in the cosine winding of a resolver rotor is at a maximum when the angle θ is equal to
    a. 0°
    b. 45°
    c. 60°
    d. 90°

11. The booster amplifier placed between two resolvers produces good voltage regulation because it
    a. has approximately unity gain
    b. is more effective when the resolver temperatures are high
    c. draws very little current from the input resolver
    d. cancels phase shift

12. The negative feedback is used in the amplifier between two resolvers in order to
    a. eliminate distortions
    b. reduce the gain
    c. increase the input impedance
    d. cancel any phase shift in the output resolver

CHAPTER 4

MECHANICAL AND ELECTRICAL CONVERSION

The numerical quantities involved in computed calculations in fire-control computers are represented by mechanical and electrical magnitudes. The numerical quantities are represented MECHANICALLY by the angle through which a shaft is rotated from a fixed reference position and the linear distance through which a mechanical element is moved from a fixed reference point. The numerical quantities are represented ELECTRICALLY by the magnitude of a voltage and the magnitude of a current.

Mechanical quantities representing numerical values can be converted to corresponding electrical quantities. The conversion may be accomplished by causing a shaft carrying a mechanical quantity to turn a potentiometer, connected as shown in figure 4–1.

Here a fixed a-c or d-c voltage is applied across the potentiometer and the output voltage taken from the arm

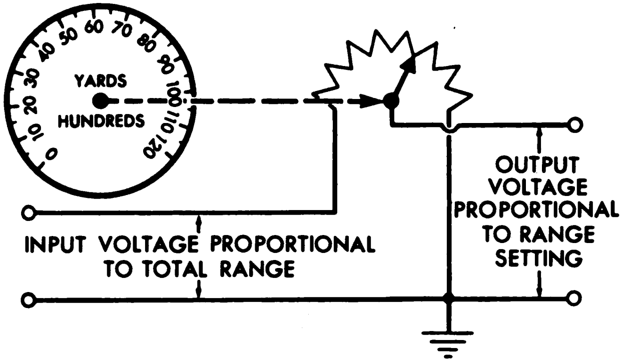

0
10
20
30
40
50
60
70
80
90
100
110
120
YARDS
HUNDREDS
INPUT VOLTAGE PROPORTIONAL TO TOTAL RANGE
OUTPUT VOLTAGE PROPORTIONAL TO RANGE SETTING

Figure 4–1.—Electromechanical representation.

and from the grounded end of the winding. When the mechanical input is zero, the potentiometer arm is at the grounded end of the winding and the output voltage is zero. The voltage output of the potentiometer is proportional to the angle through which the arm is rotated from the zero position. Thus, for any position of the input shaft, a voltage output proportional to the mechanical input is obtained.

Quantities which have both positive and negative values may also be represented mechanically or electrically. In a mechanical device, negative values are represented by moving the mechanical element in a direction opposite to that for positive values. Electrically, the sign of the quantity is represented by polarity for d-c voltages and currents or by phase for a.c. Mechanical values which may be either positive or negative can also be converted into electrical values by a potentiometer. A fixed d-c voltage is applied across the potentiometer winding and the output voltage is taken from the arm and a center tap on the winding. When the input is zero, the output voltage is also zero. If the arm is moved away from the center tap, an output voltage appears. The polarity of the output voltage is positive or negative with respect to the center tap depending on the direction of movement. The magnitude of the voltage is proportional to the angle through which the arm has been rotated from zero position. Thus, for any position of the input shaft, a voltage is obtained whose magnitude is proportional to the magnitude of the input quantity, and whose polarity with respect to the reference point indicates the algebraic sign of the input.

The principles of operation for devices converting linear displacements to electrical values are the same as for those converting angular displacements. Instead of rotary potentiometers, card potentiometers wound on a flat rectangular strip are used. The mechanical input moves the contactor across the winding in a straight line. With the electrical connections made in the same way as for rotary potentiometers, the same conversions can be accomplished.

Electrical quantities are converted to mechanical quantities by devices using the electrical signal to control a motor which positions the mechanical element.

Conversions other than mechanical to electrical, or electrical to mechanical, may also be made. Rotational mechanical values are converted to linear motion by a rack and pinion. A quantity expressed as a current may be converted to a voltage by passing the current through a resistor to obtain a proportional voltage. And many other similar conversions are possible and are used.

ELECTRICAL MULTIPLICATION

Multiplication can be performed with a potentiometer when one of the values to be multiplied is represented by a voltage and the other by a mechanical rotation. The potentiometer used for ordinary multiplication has linear resistance characteristics; that is, equal increments of resistance are obtained for equal amounts of shaft rotation. The voltage is connected across the entire winding of the potentiometer and the mechanical value rotates the shaft of the potentiometer. The output is taken from one end of the potentiometer and from its arm. Since the output voltage is proportional to both the input voltage and the angle through which the arm is rotated by the mechanical input, it is also proportional to their product.

A potentiometer multiplier can use either a-c or d-c values. If the value represented by d-c voltage input can be either positive or negative, then its polarity may be used to represent its direction. If the mechanical input is such that it can be either positive or negative, a center-tapped potentiometer must be used. The constant of proportionality between the output and the product of the inputs will be "1" for a potentiometer with no center tap, and "½" for a potentiometer with a center tap.

Another form of a multiplier is shown in figure 4–2 and is used to represent a rate by a current. It is desired that a voltage be obtained whose magnitude is proportional to the product of the rate and range. The current, which represents the rate of change of range, is passed through a potentiometer and follows the path shown by the heavy lines in figure 4–2. It does not enter the output circuit in any appreciable amount because the resistance of the output circuit is so great that, for purposes of analysis, it may be considered infinite. The drop (*E*1) caused by the flow of current through the dark portion of the potentiometer in figure 4–2 is impressed on the output terminals. *E*1 is proportional to the current and the amount of resistance through which it flows. The resistance depends upon the position of the potentiometer arm, which, in this case, is proportional to range. The output voltage, therefore, is proportional to rate times range.

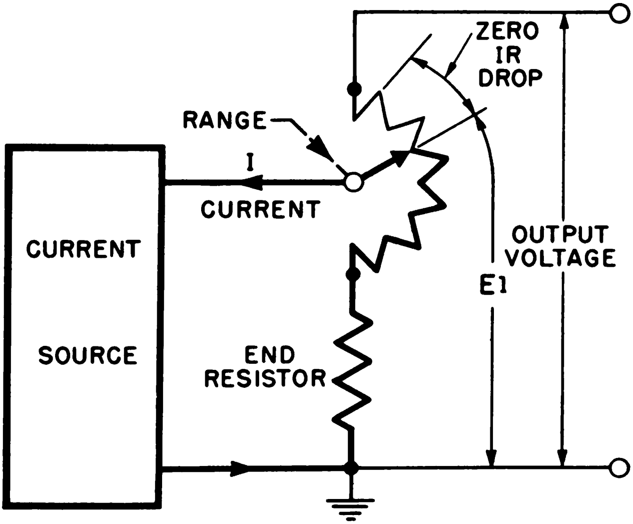


Figure 4–2.—Electromechanical multiplication.

The resistor labeled "end resistor" is used to limit the minimum range input. Because the rate current flows through this resistor, the minimum output is proportional to rate times a constant minimum range.

ELECTRICAL DIVISION

Division may be performed with a potentiometer having linear resistance characteristics when one of the values is represented by a voltage and the other by a mechanical rotation. The circuit for dividing a voltage by range is shown in figure 4–3. The potentiometer is used as a variable resistor in series with the input voltage *E*, and the mechanical input *R* rotates the arm. The output quotient voltage *Eq* is proportional to the input voltage divided by range: $Eq=k\frac{E}{R}$; where *k* is a constant or proportionality.

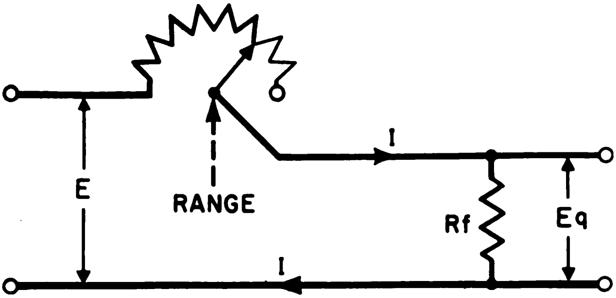


Figure 4–3.—Electromechanical division.

The minimum value of range is represented by the extreme counterclockwise position of the potentiometer.

D-C RESOLVER

The d-c resolver is an electrical device for performing trigonometric operations upon mathematical values. The inputs to the resolver are (1) the magnitude of the value expressed as a d-c voltage, and (2) its direction expressed as a mechanical rotation. Since the value has both magnitude and direction, it can be represented as a vector. The outputs of the d-c resolver are the sine and cosine components of the vector.

The construction of the resolver is shown in figure 4–4. The angle input rotates the potentiometer card with respect to the case and the four fixed contacts. The voltage input is connected across the resistance winding on the card through slip rings on the shaft. The output voltages are taken off between opposite pairs of contacts.

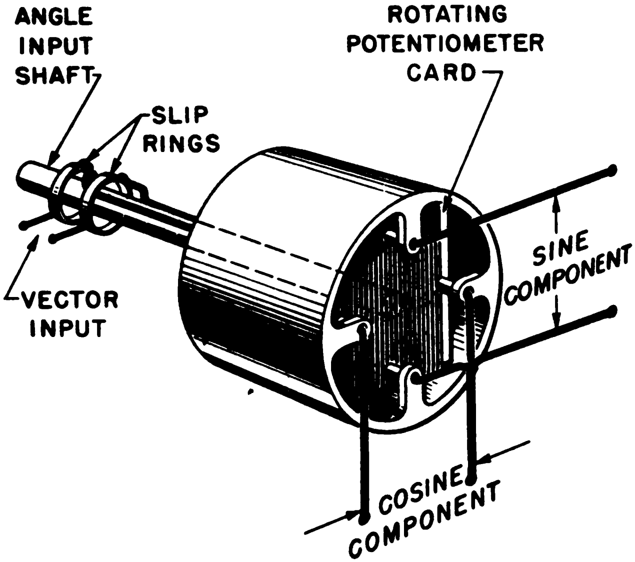


Figure 4-4.—D-c resolver.

In figure 4–5A the potentiometer card is shown at zero input angle with only the cosine contacts shown. The winding of the card is energized by a voltage (V) representing the magnitude of the input vector. The voltage across the contacts is proportional to the amount of resistance included between the contacts and, since the entire resistance is picked off by the contacts, the output voltage will be equal to the entire input voltage. In figure 4–5B the potentiometer card is shown rotated clockwise through 30 degrees. The distance between the contacts measured along the reference line is the same in figure 4–5A, but with the card rotated the distance measured in the direction of the card centerline is less. The resistance picked off is proportional to the distance measured in the direction of the card centerline which, in this case, is proportional to the cosine of 30 degrees. Hence, the output voltage is equal to the product of the input voltage and the cosine of 30 degrees.

When the card is rotated 90 degrees, both contacts touch the same coil of the winding. The resistance now picked off by the cosine contacts should be zero, but since the contacts are separated by the width of the card, the resistance of one-half of turn is included between them. The resistance of one-half of one turn is so small compared to the total resistance of the potentiometer that the voltage drop may be considered zero for practical purposes.

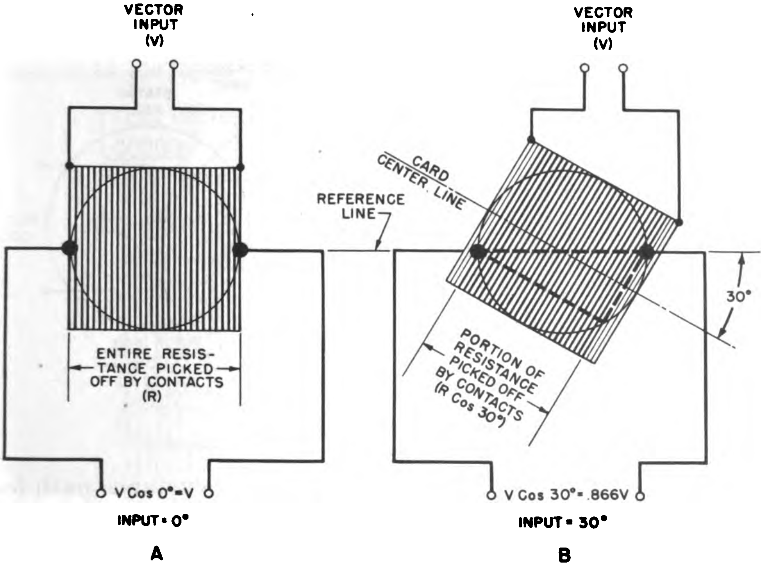


Figure 4–5.—D-c resolver operation.

As shown in figure 4–4, the sine contacts are located 90 degrees from the cosine contacts. Thus, when the card is at zero degrees, the voltage picked off by the sine contacts is zero, and at 90 degrees the voltage picked off is the full input voltage.

A-C RESOLVER

The a-c resolver has its magnitude expressed as an a-c voltage and performs the same function as the d-c resolver. The wiring schematic of the a-c resolver is shown in figure 4–6B, and the general construction of the resolver is shown in figure 4–6A.

In the application of the a-c resolver discussed here, the input voltage representing the magnitude of the vector is impressed across the terminals of the stator coil shown in the heavy dark lines in figure 4–6A. The mechanical input representing the direction of the vector turns the rotor. The current which flows in the stator coil sets up a field of flux which follows the paths shown by the flux lines in the figure.

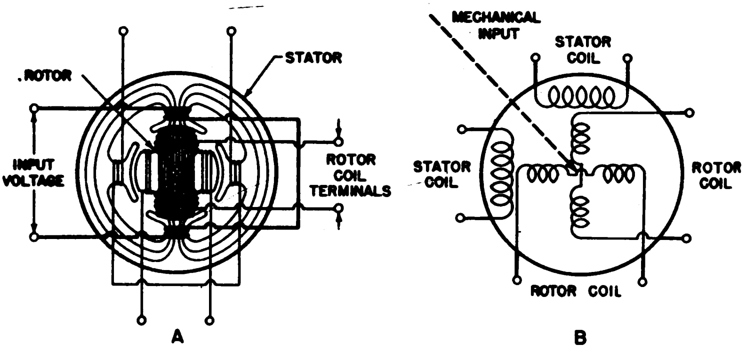


Figure 4–6.—A-c resolver.

The iron core of the rotor provides a low reluctance path for the flux. It does not distort the field while it is rotated because it is nearly circular in cross section. Thus, for any position of the rotor, the rotor coils lie in a uniform rectilinear flux whose strength is directly proportional to the magnitude of the input voltage. The field induces voltages in the rotor coils which are proportional to the sine and cosine components of the input vector for the angle through which the rotor has been turned. The rotor winding shown in dark lines in figure 4–7A is the cosine winding and the other is the sine winding. Electrically the rotor is at zero angle.

Figure 4–7A shows the cosine coil of the rotor in the field with the rotor at zero. The vector represents the strength of the field. All of the flux threads the coil axially, and the voltage induced in the coil is at a maximum.

Figure 4–7B shows the coil rotated through 90 degrees. The axis of the coil is now perpendicular to the direction of the flux. The component of the flux vector in the direction of the axis of the coil is zero, and hence the voltage induced in the coil is zero. This corresponds to the fact that the cosine component at 90 degrees is zero.

Figure 4–7C shows the cosine coil rotated through an angle (A) between zero and 90 degrees. In this position of the rotor the flux vector has a component in the direction of the axis of the coil which is proportional to the cosine of *A*. The voltage induced in the cosine winding is, therefore, proportional to the product of the input voltage and the cosine of the angle.

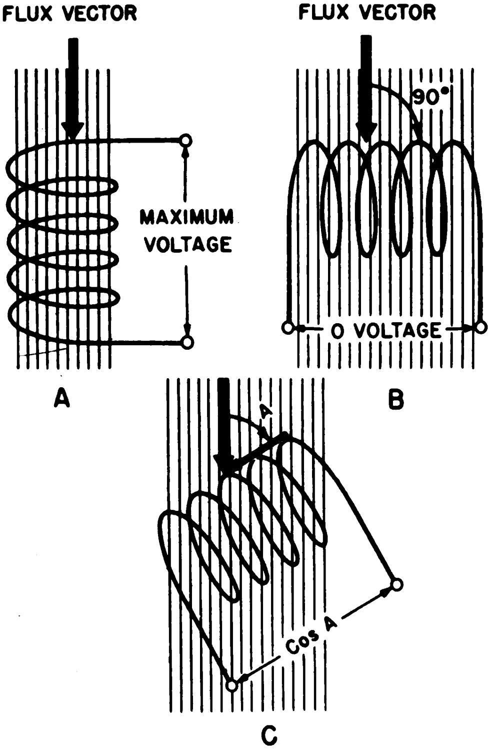


Figure 4–7.—A-c resolver operation.

The sine rotor winding has its axis perpendicular to the axis of the cosine winding and hence the voltage induced in it is proportional to the sine component of the input vector. At zero position of the rotor the axis of the sine winding is perpendicular to the direction of the flux and the voltage induced in it is zero. At 90 degrees the axis of the sine winding is parallel to the direction of the flux, and maximum voltage is induced.

QUIZ

1. Quantities which have been both positive and negative values may be represented
   a. only mechanically
   b. only electrically
   c. mechanically or electrically
   d. only if the quantity is made positive
2. The output voltage of a potentiometer is proportional to the angle through which the arm is rotated from
   a. the center of the potentiometer
   b. the zero position
   c. the 90° position
   d. any position
3. A d-c voltage is applied across a potentiometer winding and the output voltage is taken from
   a. the arm
   b. the center tap
   c. any point and ground
   d. the arm and center tap
4. In electrical multiplication with a potentiometer the output is taken from
   a. one end of the potentiometer and its arm
   b. input end and ground
   c. both ends of the potentiometer
   d. the arm and either end of the potentiometer

True and False

5. The resistor labeled "end resistor" in figure 4–2 is used to limit the maximum range input.
6. Division may be performed when one value is represented by a voltage and the other by a mechanical rotation if the potentiometer has linear resistance characteristics.

7. An electrical device for performing trigonometric operations upon mathematical values can be called a d-c resolver.
8. The output of a d-c resolver is equal to the sum of the input voltage and the sine or cosine of the angle.
9. When the potentiometer card is at zero degrees, figure 4–4, the voltage picked off by the cosine contacts is zero.
10. Numerical quantities are represented electrically by the magnitude of a voltage and the magnitude of the current.

CHAPTER 5

LINKAGE COMPUTING MECHANISMS

Until recently, linkages were not widely used as computing mechanisms in fire-control equipment. Where they were in use, there was little chance for Fire Control Technicians to learn their operations. For example, in the early days of World War II an AA barrage computer was supplied to vessels which had no AA directors. This computer proved useful in computing sight angle, sight deflection, and fuse time for manual introduction at the individual guns. Fleet personnel, however, did not service this barrage computer, so there was little opportunity for Fire Control Technicians to become acquainted with the linkage type of computing mechanisms.

Since that war, however, the Navy has approved the use of these mechanisms in various computers. The most common is the Computer Mk 42, which is a part of the GFCS Mk 56. Another is the Attack Director Mk 4. Since the linkage used in the Computer Mk 42 and the Attack Director Mk 4 are designed to be adjusted aboard ship, the Fire Control Technician must have a working knowledge of the theory of operation and the mechanics of linkage mechanisms.

Linkage mechanisms which solve ballistic equations are, in some respect, superior to cams because they have less friction. Also, ball and roller bearings can easily be adapted to linkage mechanism so that mechanical power amplifiers are not necessary. In addition to being free from excessive internal friction, a linkage mechanism can be made compact, mechanically rugged, and nonresonant below 30 cycles per second.

Due to differences in ballistics and improved methods of computation introduced in later models, the linkage computing mechanisms differ widely among various machines. However, they all use the same basic elements and have the same general type of construction. Therefore, our examination of linkages begins with the linkage elements which are considered fundamental because they cannot be further broken down.

FUNDAMENTAL COMPONENTS

A photograph of one linkage computer now in use is shown in figure 5–1. The figure shows that several familiar units including shafts, bearings, racks, and pinions are used in the linkage computer. However, since certain applications of these units are new, they will be discussed along with the special mechanisms found only in linkage computers.

Figure 5–2 shows a shaft assembly from the linkage unit with its bearings and bearing support. In this example, the

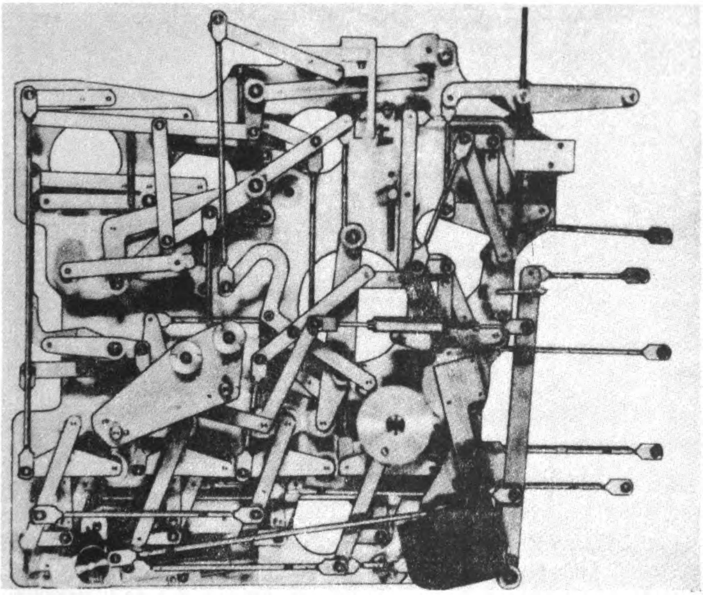


Figure 5–1.—Top view of a linkage computer.

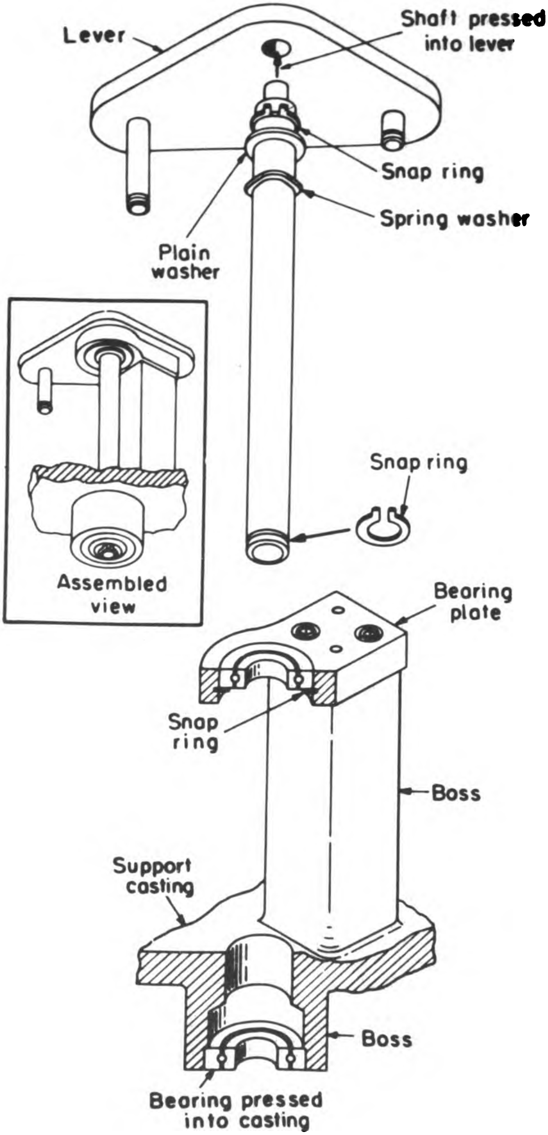


Figure 5-2.—Typical shaft assembly.

lower bearing is seated in a boss on the under side of the linkage support casting; the upper bearing is carried in a plate secured by screws and dowels to a boss on top of the casting. Both bearings are pressed into their seats and staked in place. Some bearings, like the lower one in the illustration, are seated against machined shoulders; others, like the upper one, are seated against snap rings set in grooves.

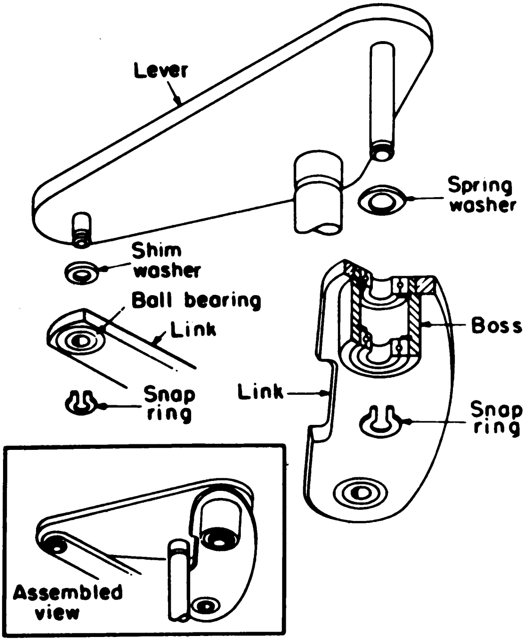


Figure 5-3.—Two types of link connections.

The shaft is grooved near the top and bottom to receive snap rings which hold it in place. A spring washer and a plain washer are assembled between the upper bearings and snap rings to prevent end play. The lever or gear carried by a shaft is usually pressed on and may be seated against a shoulder which is accurately spaced from the lower snap ring groove to place the gear or lever at the proper level.

Figure 5–3 shows two constructions which are used to connect levers and links. The connection at the left end of the lever is generally used for links which are supported at both ends. A small bearing is seated in the end of the link and is staked in place. A pivot pin pressed into the left end of the lever fits the ball bearing bore. The link is assembled on the pivot pin with a shim washer to provide the proper spacing and a snap ring to hold it in place.

The connection of the link to the right end of the lever in figure 5–3 is used for links which can be supported at only one connecting point. A boss is pressed into the link at the end at which it is to be supported, and two ball bearings are seated against snap rings in the boss. The link is assembled on the pivot pin with a spring washer, to prevent lost motion, and a snap ring to hold it in place.

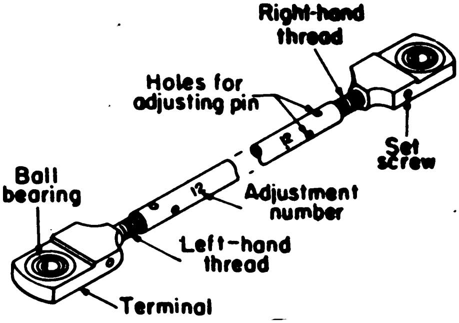


Figure 5–4.—Adjustable links.

Adjustable links are used for alignment in numerous places in the linkage system. Each such link consists of two terminals and a tubular rod fastened together by right- and left-hand threads, as shown in figure 5–4. A ball bearing is seated in each terminal to make low friction connections to other links, levers, or slide bars. With both terminals held from turning, the length of the link can be adjusted on the turn buckle principle by inserting an adjusting pin in one of the holes provided for the purpose of turning the rod. The set screws in the terminals lock the adjustment and must be loosened before a change in length is attempted. Adjustment points in the linkage assembly are numbered to aid in following alignment instructions, and the corresponding number is engraved on each of the adjustable links.

At a number of points in the linkage mechanisms it is necessary to make angular adjustments of a crank arm, lever, or gear on its shaft. The construction shown in figure 5-5 is known as a compound crank, and is provided for this purpose. The lower arm is pressed on, whereas the upper arm fits freely on the shaft. A crank pin on the outer end of the lower arm projects upward into a hole in the upper arm, but since the pin is much smaller than the hole, considerable relative movement between the two arms is possible.

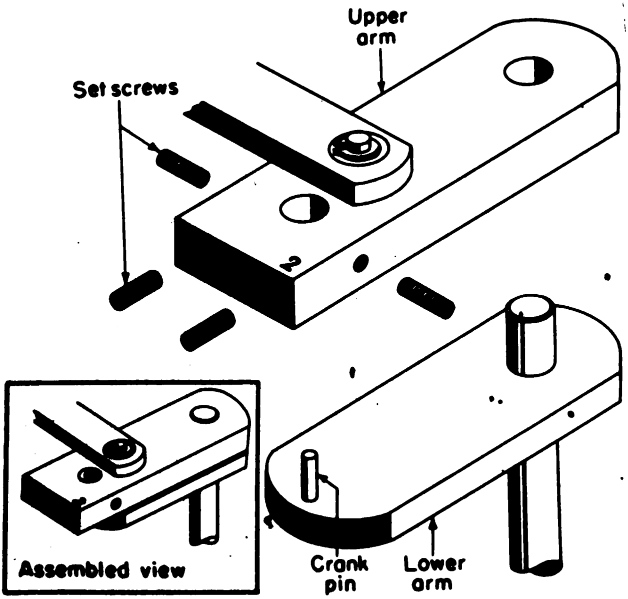


Figure 5-5.—Angular adjustment.

Two set screws, threaded in opposite directions on opposite sides of the upper arm, engage the crank pin to hold the two arms in a fixed relative position. This position can be adjusted by backing off one set screw and turning in the other. The adjustment is locked by two additional set screws, threaded in the end of the upper arm, which bear against the first pair of screws.

Some of the quantities involved in the equations solved by linkage mechanisms are represented by a straight line motion of a slide bar such as that shown in figure 5–6. The movements of the bars or racks are guided by rollers, each of which is a small roller bearing mounted on a block. This combination is known as a roller block and comes in different forms. The illustration shows four different forms. The two roller blocks on the right side of the bar are secured to the fixed structure; those on the opposite side are mounted on pivot pins. Tension springs rock the pivoted blocks to bring their rollers into contact with the bars thereby pressing the bar firmly against the fixed rollers. For greater stability, one of the fixed blocks carries two rollers, one engaging the bar near the top of the rack gear and the other near the bottom.

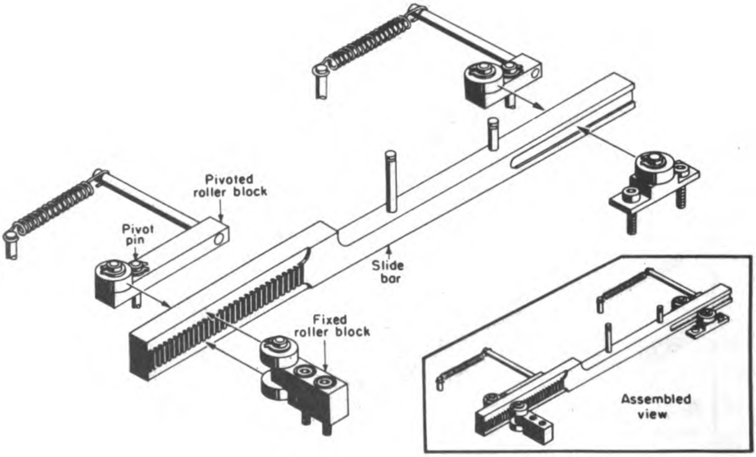


Figure 5–6.—Typical slide-bar assembly.

Motion is transmitted to or from the slide bar by means of links or by racks and pinions. Figure 5–6 shows rack teeth cut in one side of the bar and two pivot pins for linkage connections on the top.

ADDING AND SUBTRACTING LINKAGES

Addition of two quantities is performed in the linkage mechanism by means of adding levers as shown in figure 5–7. In the example, two quantities, designated *X* and *Y*, are to be added and their values are represented by the movements of the two slide bars. The adding lever is pivoted at its center to another slide bar and its opposite ends are connected through links to the *X* and *Y* slides. To illustrate the problem, scales showing the values of the quantities represented by movements of slides have been drawn in the figure and index marks are placed on the slides. The units on the center scale are half as large as those on the other two.

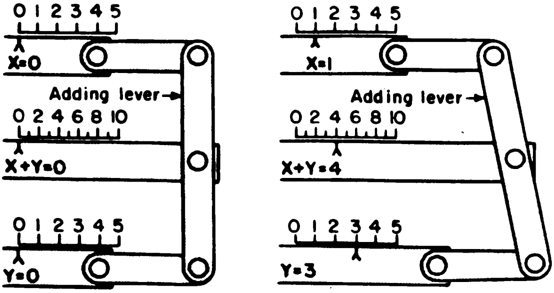


Figure 5–7.—Adding lever.

If the *Y* slide is held in place and the *X* slide is moved, the adding lever pivots about its lower end. The center slide which is connected to the midpoint of the lever then moves half as far as the *X* slide. If the *X* movement is one unit, the center slide also moves one unit, since the units on the center scale are half as large as those on the *X* scale. Similarly, movements of the *Y* slide with the *X* slide held in place add one unit on the center scale for each unit movement of *Y*. At the left of figure 5–7 the parts are shown in zero position, with the three index marks opposite the zero points of the scales. At the right, the *X* slide has been moved one unit, and the *Y* slide has been moved three.

The center slide has traveled one unit in response to the

X-travel and three more in response to the *Y*-travel and so stands at a reading of four. Similarly, for any position of the *X* and *Y* slides the reading on the center scale represents the quantity *X* plus *Y*.

There are several variations of the adding lever used in the computing linkage. In most cases the problem calls for the addition of multiples of two quantities, for example 2.3 *X* plus 3.4 *Y*. Then the connection of the output slide to the adding lever is placed off center, the desired output being obtained by a proper choice of the connecting point. Subtraction is accomplished by moving one of the inputs in the opposite direction for positive values or by placing the output at one end, one input at the other end, and the second input in the middle. The quantities to be added or subtracted may be represented by the movements of links driven by levers, rather than slides, and the output may be transmitted to a lever. The slides are used in the illustration merely as an example.

ADDITION OF CONSTANTS

The two quantities *X* and *Y* which are added by the lever as shown in figure 5–7 may be continually changing in value throughout a firing problem. Such quantities are known as VARIABLES. Quantities which always have the same value are called CONSTANTS and can be added or subtracted at any point in the mechanism by proper zeroing procedures. As an example, assume that the link joining the *X* slide to the lever in figure 5–7 is adjustable and is used in zeroing. Then, if it is desired only to add *X* and *Y*, the length of the link is adjusted to place the *XY* index at zero when *X* and *Y* are both at zero. But, if the equation to be solved calls for the addition of a constant, say 2, at this point, the adjustable link is set to place the *XY* index at 2 when the *X* and *Y* are at zero. The output scale then reads *X* plus *Y* plus *2* for all values of the variables *X* and *Y*.

MULTIPLYING LEVERS

Multiplication in which one of the factors is a constant is performed by multiplying levers as shown in figure 5–8. In the example it is desired to transform a movement representing the quantity X into one representing $1.5X$. One end of the multiplying lever is pivoted on the fixed frame of the computer, as indicated by the cross-hatched circle in the figure.

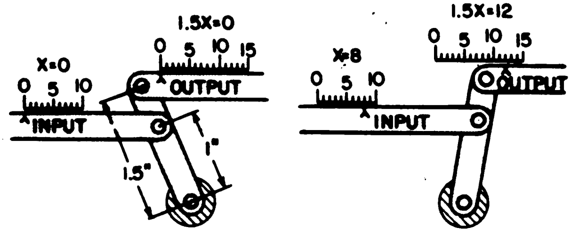


Figure 5–8.—Multiplying lever.

The input link and output link are connected to the lever at different points, the connection of the output link being 1.5 times as far from the fixed pivot as the connection of the input link. The two scales shown in figure 5–8 have units of the same size, but due to the difference in lever arms, each one-unit movement of the input link moves the output link a unit and a half. Then, if the input movement represents the quantity X, the output represents $1.5X$.

BELL CRANKS

Bell cranks are used primarily to transmit motion from a link traveling in one direction to another link which it is de-

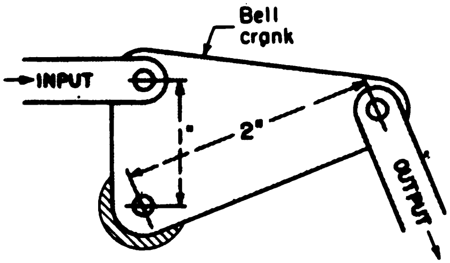


Figure 5–9.—Bell crank.

sired to move in a different direction. The bell crank is mounted on a fixed pivot, and the two links are connected at two points in different directions from the pivot. By properly locating the connection points, the output links can be made to move in any desired direction. By setting the connection points at different distances from the fixed pivot, the bell crank can also be made to serve as a multiplying lever. In the example shown in figure 5–9, the output lever arm is twice the length of the input lever arm. Then if the input movement represents a quantity X, the output represents $2X$.

MULTIPLYING LINKAGES

In several cases the computing problem requires the multiplication of two variable quantities. The multiplying levers shown in figure 5–8 cannot be used for this purpose

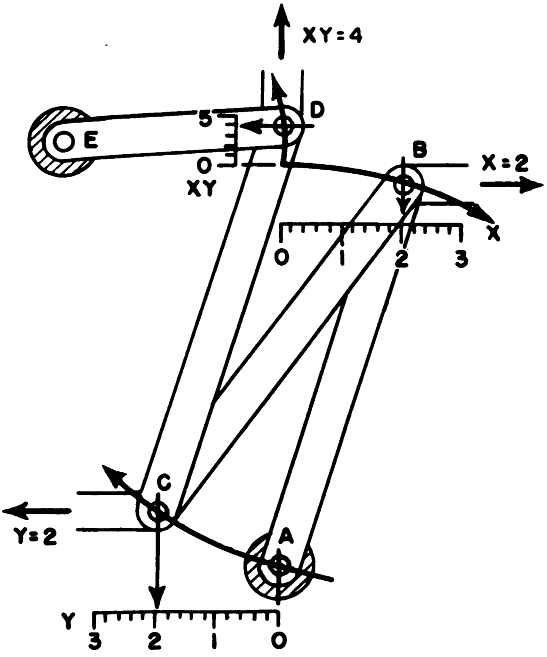


Figure 5–10.—Multiplying linkage.

since with these levers one of the factors is introduced by choosing the lengths of the lever arms, and these lengths can not be changed to suit the changing values of a variable. Figure 5–10 shows a linkage designed to multiply two variables X and Y, and several such linkages are used in the linkage computer. The levers AB and ED are pivoted on the fixed structure and are connected by links BC and CD, both of which have exactly the same length as AB. The X input is applied by a link connected at B or connected to lever AB at some other point. The Y input is applied by a link connected at C and the output XY is taken off at D. In the position of the links shown in figure 5–10, X equals two units, Y equals two units, and XY equals four.

One such linkage in the computer is operated in reverse to serve as a divider instead of a multiplier. Two inputs are applied at the points corresponding to B and D in figure 5–10. The output taken off at C then represents the input at D divided by the input at B.

Another type of multiplying linkage used is shown in figure 5–11. In the computer the linkage is operated in

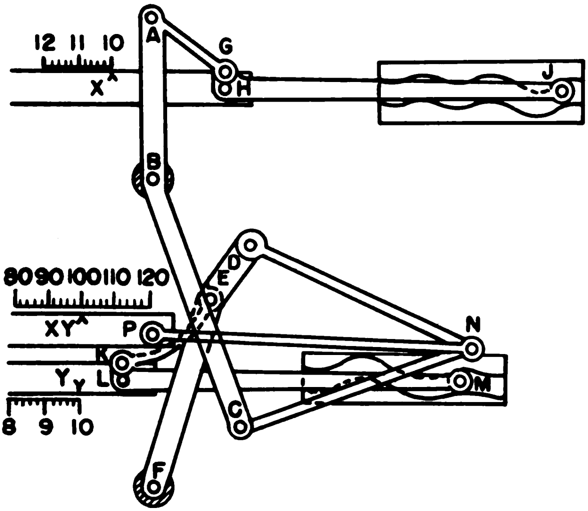


Figure 5–11.—Multiplying linkage.

reverse as a divider, but since it is inherently a multiplying linkage it will be described as such. The two quantities *X* and *Y* to be multiplied are introduced by slide bars which drive levers *ABC* and *DEF*, respectively. The connection between the *X* slide and lever *ABC* is through link *AG* and bell crank GHJ. The bell crank is pivoted to the slide at *H* and carries at *J* a ball-bearing roller riding in a cam groove. Between the *Y* slide and lever *DEF* there is a similar connection consisting of link *EK* and bell crank *KLM* with a roller and cam at *M*. The two levers are tied by links *CN* and *DN* to link *NP* which drives the *XY* slide.

If the levers *AG* and *EK* were connected directly to the slides *X* and *Y*, the movement of slide *XY* would represent approximately the product of *X* and *Y* on the scales as shown in figure 5–11. However, the two cams have the effect of changing the positions of the connecting points *G* and *K* during the travel of the slides, and thus add to or subtract from the movements of the levers. The cams are shaped in such a manner that this additional movement materially increases the accuracy of the *XY* output.

The linkage just described can not be used for problems in which either *X* or *Y* has a zero value or a value close to zero. Since it is used as a divider in the computer, the inputs are introduced on the *XY* and *Y* slides and the output is taken from the *X* slide; that is, it divides *XY* by *Y* to obtain *X*.

FOUR-BAR LINKAGES

Four-bar linkages are used as a short-cut in computing quantities which would otherwise require a combination of several adding levers and multiplying linkages, and in computing ballistic quantities which are determined as a result of experimental firing rather than mathematical analysis. This linkage consists of two levers, *AB* and *CD*, pivoted on the fixed structure and connected by a link *BC*. The fixed structure is the fourth bar which gives the linkage its name. In the example of figure 5–12 the input is applied at *B* and the output is taken off at *C*.

In some linkages the input is a shaft rotation applied at

A and the output can be taken from the shaft at *D* or can be taken off by a link as in the illustration, figure 5–12. The relation between the output and input depends on the relative lengths of the four bars. These lengths can be chosen to fit the output to a wide variety of mathematical and experimental quantities within the degree of accuracy required by the fire-control problem.

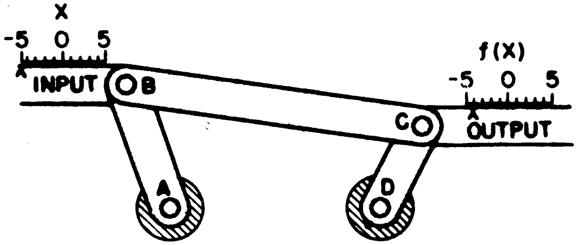


Figure 5–12.—Four-bar linkage.

Since the output of the four-bar linkage does not have a simple mathematical relation to the input, it is usually spoken of simply as a FUNCTION of the input. The symbol $f(X)$ in figure 5–12 is read FUNCTION OF X and indicates merely that the output is a variable quantity whose value depends on the value of the input quantity X.

SINE AND COSINE RESOLVER

The only trigonometric quantities used directly in the equations solved by the computer are the sine and cosine of the angle *E*. These quantities are determined by the sine and cosine resolver shown disassembled in figure 5–13. The crank disk is pressed on a shaft which is carried in ball bearings in a support casting, as shown in the assembled view in figure 5–13, and which mounts two gears at its lower end. The lowermost of these gears is driven at 1-speed by the gear on the shaft of the elevation coupling which transmits the *E* input to the resolver. The second gear transmits *E* to other computer mechanisms.

The sine and cosine crank pins are seated in bushings in the crank disk and each carries a pinion meshing with a sta-

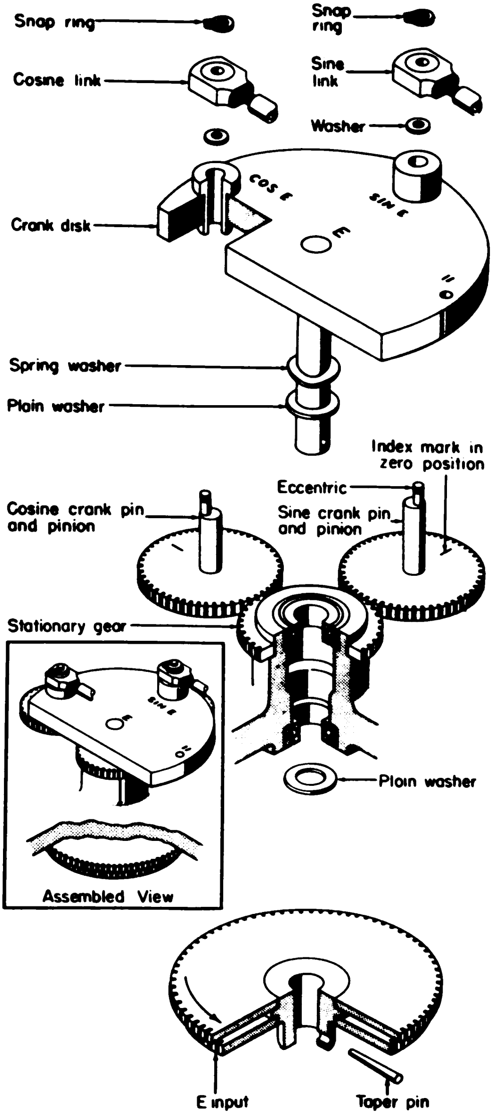


Figure 5–13.—Sine and cosine resolver.

tionary gear mounted on the support casting. The sine and cosine links are pivoted on eccentrics on the upper ends of the crank pins, and these links drive the sine *E* and cosine *E* slide bars.

If the sine and cosine links could be made long enough, they could be pivoted directly on the axes of the crank pins instead of on eccentrics. They would then give reasonably accurate sine and cosine travel to the slide bars. However, available space limits the lengths of the links, and with relatively short links, errors are introduced by changes in the angular positions of the links during their travel. These errors are corrected by the use of the eccentrics.

As the crank disk is turned, the pinions roll on the stationary gear, turn the crank pins, and throw the eccentric through 180 degrees for a 90-degree movement of the disk. At zero value of *E* the sine eccentric should be on the side of the crank pin nearest the slides, and the cosine eccentric should be on the opposite side. At 90 degrees of *E* these positions are reversed. Index marks are provided on the two pinions to aid in assembling them with the eccentrics in the proper positions. At zero degree of *E* the index marks should line up with the centers of the crank pins and the center of the crank-disk shaft.

Another type of sine and cosine resolver is shown in figure 5–14. This type of resolver computes either the sine or cosine but not both, thus, two units are required instead of one. The cosine resolver is shown partly disassembled in figure 5–14. The shaft is turned at 1-speed by the input from the *E* coupling, through gears. An adjustable arm is mounted on the upper end of the shaft and carries a second arm pivoted on an axis offset from the axis of the shaft. This arm carries a pinion above and the cosine pin below. The pinion is doweled to the arm and meshes with a fixed internal gear. The cosine pin provides the connection from which the output of the unit is taken.

The diagram at the top of figure 5–14 shows the relation of the parts for an elevation angle *E* of approximately 45 degrees. As the angle increases, the adjustable arm turns clockwise, and the pinion rolls counterclockwise. The cosine

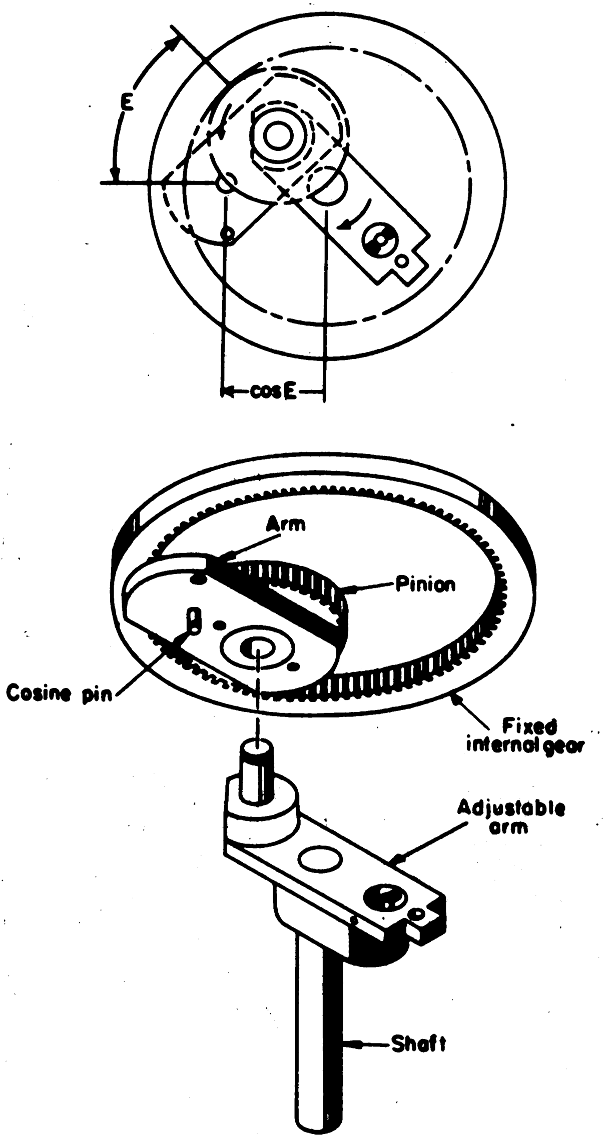


Figure 5-14.—Sine or cosine resolver.

pin then moves in a straight line directly toward the axis of the shaft. When E is 90 degrees, the pin is directly over the shaft. As E decreases, the pin moves directly away from the shaft and reaches its maximum distance when E is zero. For any value of E the distance between the shaft center and the center of the cosine pin is proportional to the cosine of E.

The sine resolver is similar to the cosine resolver, but it is zeroed with the pin over the shaft for zero value of E. Since both the sine pin and cosine pin move in straight lines, it is not necessary to add slide bars to give straight line movement. Therefore, the pins are connected directly to the multiplying linkages.

ABSOLUTER

The absoluter is a linkage device used to convert linear motions of either a positive or negative value into linear motions that are always positive, and is used in the Attack Director Mk 4 in the computation of firing time. Time can never go negative, it is either in the present or the future; thus, firing time is always positive. However, some of the quantities used in the computation of firing time can be negative, so we must find a way to make the output of firing time positive regardless of the sign of the input quantity. This is accomplished with the absoluter.

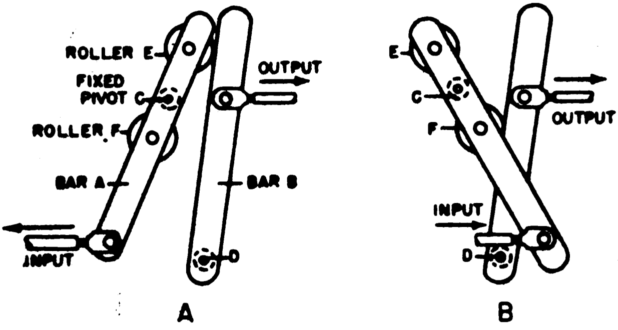


Figure 5-15.—The absoluter linkage mechanism.

Figure 5–15 shows the absoluter linkage. Any movement of the input linkage to the left causes roller *E* to push against bar *B*, thereby moving the output link to the right a distance which is proportional to the input. Likewise, motion of the input link to the right causes roller *F* to push against bar *B* and moves the output link to the right a distance which is proportional to the input.

The absoluter is composed of two lever type multipliers connected in series. Bar *B* works on exactly the same principle as the lever multiplier, but the action of bar *A* is a little different. You have one multiplier when roller *E* is active, figure 5–15A, and another when roller *F* is active, figure 5–15B. Thus, bar *A* serves as a duplex-lever multiplier.

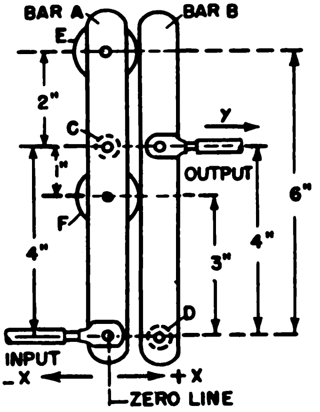


Figure 5–16.—The multiplying ratios of the absoluter.

The dimensions of the absoluter shown in figure 5–16 are typical, and from them we can set up our mathematical relations. With a positive input, the input link moves to the right and roller *F* becomes active. The input quantity, x is then multiplied by $\frac{1}{4}$. This ratio is formed by the relative distances that roller *F* and the input link are located from the fixed pivot *C* in figure 5–16. The roller *F* becomes the input to bar *B*. This rightward motion of roller *F* is therefore multiplied by the ratio $\frac{4}{3}$.

Figure 5–16 shows that the point of contact of roller *F* is three inches from the fixed pivot *D* of bar *B*, therefore,

$$y=x\left(\frac{1}{4}\cdot\frac{4}{3}\right)=\frac{x}{3}$$

if a negative *x* is applied, it moves the input link to the left of the zero line as shown in figure 5–16. The rightward movement of roller *E* is then proportional to the ratio formed by the distance roller *E* and the input link are located from the fixed pivot *C*. The output of roller *E* is therefore equal to the input quantity *x* multiplied by ¾, the ratio formed by the arms on each side of pivot *C*.

The motion imparted to roller *E* now becomes the input to bar *B* and is multiplied by the ratio 4/6, which is taken from the dimensions shown or

$$y=x\left(\frac{2}{4}\cdot\frac{4}{6}\right)=\frac{x}{3}.$$

Note: Although *x* is negative in direction, the minus sign has been omitted here for simplicity.

The output of the absoluter is thus equal to one-third of the input when *x* is either positive or negative. The constant 3 can be cleared from the denominator by multiplying the output with a lever multiplier.

NONLINEAR LINKAGES

Ballistic quantities such as drift and superelevation are usually computed as empirical functions of range and elevation, and can be reproduced mechanically by cams or linkage mechanism.

Before discussing the nonlinear linkage let us briefly study the linear four-bar linkage shown in figure 5–17. The fourth bar is composed of the distance between the fixed pivots *M* and *N*. The input and output levers are connected by a free link whose pivots are the same distance apart as the fixed pivots *M* and *N*. We then have $y=\frac{xbd}{ac}=\frac{xd}{a}$, where lengths *b* and *c* cancel because they are equal. The graph in, figure 5–17B shows that y varies directly with x, that is, in a linear fashion. If the ratio d/a is changed, the slope or slant of the line will vary, but even so, the resulting line will always be straight.

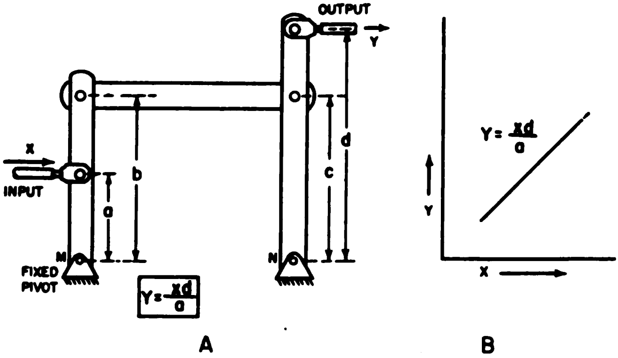


Figure 5–17.—Linear four-bar linkage.

Although straight line functions are useful in fire-control computers to make approximations, the curved function is the one most often encountered.

The graph shown in figure 5–18B displays a curve in which y is shown as a function of x. y is the dependent variable whereas x is the independent variable. Therefore, y might correspond to the ballistic, and x to range or elevation.

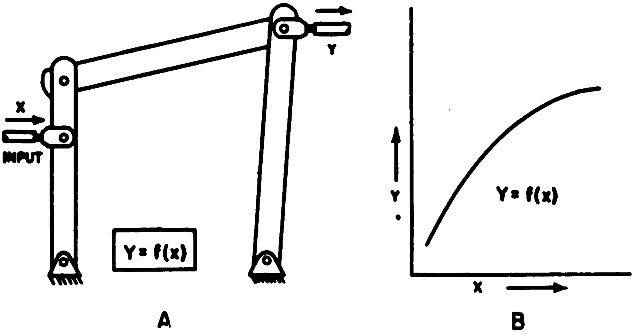


Figure 5–18.—Nonlinear four-bar linkage.

The nonlinear linkage of figure 5–18A computes the curved function of 5–18B. In contrast to the linear linkage shown in figure 5–17A, you will find that no two bars of the nonlinear linkage are equal in length.

Thus, the relative lengths of the input and output levers, the free link, the fourth bar, and the spacing of the input and output links from the pivot points are chosen to fit the particular equation. The nonlinear four-bar linkage will appear in numerous arrangements and should be easily recognized.

QUIZ

1. Which of the following does not describe an advantage of linkage mechanisms?
   a. They can be designed so that the mechanical advantage will overcome bearing friction
   b. They are superior to cams in that they have much less friction
   c. They are rugged and more compact
   d. They can be designed to be nonresonant below the critical frequency of 60 cycles
2. Addition in linkage mechanisms is accomplished by moving
   a. the output link up
   b. one input link up and the other down
   c. the output link down
   d. both input links in the same direction
3. What usually holds the crank pin of the angular adjustment linkage in place after it has been correctly positioned?
   a. Set screws
   b. A weld
   c. Bolts
   d. Rivets
4. The device best adapted for converting linear motion into circular motion is the
   a. link
   b. boss
   c. slide bar
   d. roller block

5. Which of the following statements pertaining to the adjustable link is incorrect?
    - a. It has a tubular rod having right-hand threads at each end
    - b. It enables the alignment of linkage components to give accurate computations
    - c. The terminals are held rigid by means of set screws
    - d. It is adjusted by turning the tubular rod with a pin placed in one of the holes provided

6. Springs are used in the typical slide-bar assembly to
    - a. take up lost motion
    - b. prevent gear chatter
    - c. rock the pivoted roller blocks
    - d. decrease the guide roller blocks.

7. When the output of a linkage mechanism has a constant in the denominator, this constant can be made equal to one by running the answer through a
    - a. resolver
    - b. absoluter
    - c. differential
    - d. lever multiplier

8. Division can be performed with a multiplier by
    - a. reversing the X and Y inputs
    - b. exchanging the output with either input
    - c. placing a bell crank in the output
    - d. altering the position of the Y input link

9. The absoluter can be compared to the combination of
    - a. a bell crank and a lever multiplier
    - b. two bell cranks
    - c. two lever multipliers
    - d. a linkage and bell crank

10. What is the relation between the multiplication factor of the absoluter shown in figure 5–15 and the position of the rollers?
    - a. With both rollers against bar B the factor increases
    - b. With the lower roller against bar B the factor increases
    - c. With the upper roller against bar B the factor increases
    - d. The factor remains constant regardless of the position of the rollers

11. The sine and cosine crank pins of an angle resolver are located
    - a. 30° apart
    - b. 60° apart
    - c. 90° apart
    - d. 45° apart

12. What is the value of the cosine link of an angle resolver when the angle gear is set at 45°?
   a. 0.0
   b. 0.5
   c. 0.707
   d. 0.866

CHAPTER 6

AMPLIDYNE CONTROL CIRCUITS, POWER DRIVE, MK 4

The amplidyne generator is a good power amplifier that is used to drive heavy gun mounts and directors, but producing the power is not enough. The amplidyne power output must be controlled.

You already know from *Basic Electricity*, NavPers 10086, that the control fields determine both the polarity and the strength of the amplidyne output. Now we will see how the control fields get their inputs.

The control field inputs come from a number of circuits called control circuits, which amplify and rectify a control signal and then feed this signal to the amplidyne control field.

AMPLIDYNE POWER DRIVE, MK 4

Figure 6–1 shows a complete example of amplidyne control for the Amplidyne Power Drive, Mk 4. The four blocks shown in figure 6–1 contain the circuits which amplify and rectify the signal inputs. Practically all amplidyne control circuits contain these four blocks. Thus, the Mk 4 drive will give you a good idea of how every amplidyne control circuit works.

First of all, find the signal sources for the blocks. By tracing out the heavy lines you will find three separate signal sources: the COARSE synchro system, the FINE synchro system, and the LOCAL TACHOMETER GENERATOR. At all times one of these three signal sources furnishes the input to the control circuits.

Two control transformers provide fine and coarse control. In this circuit the fine signal is shorted out when the error reaches 2.5 degrees. The shorting-out is accomplished by a relay coil in the synchronizing circuit (block A). The relay closes at 2.5 degrees of error and shifts control to the coarse signal.

The local tachometer is a small d-c generator geared to the local control handwheels. The speed of the handwheels determines the strength of the generator output. The direction of rotation of the handwheels determines the polarity of the generator output. Thus, the signal from the local tachometer measures both speed and direction.

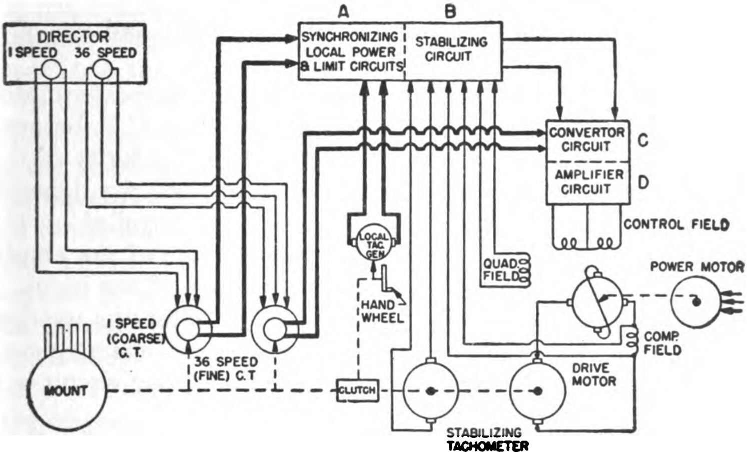


Figure 6–1.—Amplidyne Power Drive, Mk 4.

Figure 6–1 shows the three inputs to the stabilizing circuit (block B). One input comes from the quadrature field of the amplidyne. Another comes from the amplidyne compensating field. The third input comes from the stabilizing tachometer. These three inputs are fed back to combine with the fine signal to reduce hunting and jitter. For this reason the three inputs to the stabilizing circuit are called stabilizing voltages.

To get a better idea of the purpose of each block in figure 6–1, trace the FINE signal through the system.

The fine signal originates at the fine C. T. Then it goes to the CONVERTER circuit (block C) where it is rectified and combined with the stabilizing voltages from block B. The converter circuit is sensitive to phase and polarity. "Phase-sensitive" means that the polarity of the converter output depends on the phase of the input signal. In other words, if the phase of the input is reversed, the polarity of the output is also reversed. Next, the rectified output of the converter becomes the INPUT to the amplifier. This amplifier is a d-c push-pull circuit which amplifies a d-c input and delivers a d-c output. Then the amplifier output is fed to the amplidyne control fields. The amplidyne builds up the signal and feeds it to the armature of the power motor. Finally, the power motor drives the mount and the fine C. T. in response.

The direction of rotation and the speed of the power motor are controlled by the original signal at the fine C.T. because the direction of rotation is controlled by the polarity of the converter output and the converter output polarity depends on the phase of the signal. The speed is controlled by the strength of the signal because the magnitude of the amplidyne output is controlled by the magnitude of the input.

The stabilizing voltages are picked up across the quadrature field, the compensating field, and the stabilizing generator. All of them are fed back to the stabilizing circuit and combine with the signal.

The coarse C.T. signal and the local tachometer signal would go through the control circuits in about the same way, except that when the coarse signal has control, the fine signal is shorted out by a relay in the converter circuit. When the local tachometer has control, the fine signal is shorted out and the course signal circuit is opened by the selector switch.

Let's review the different inputs to the converter circuit. First are the d-c inputs from the local tachometer and the coarse C.T. The coarse C.T. input is rectified to make it d. c. Second, there are the stabilizing voltages. These are considered to be d. c. because their frequency is low compared to the 60-cycle frequency. Finally, there are the a-c inputs from the fine C.T.

To sum up the inputs to the converter, they are both d. c.

and a. c. This means that the converter circuit is sensitive to the POLARITY of the d-c signals and to the PHASE of the a-c signals.

CONVERTER-AMPLIFIER CIRCUIT

A schematic diagram of the combined converter-amplifier circuit in the Amplidyne Power Drive, Mk 4 is shown in figure 6–2. The converter and amplifier are combined because they are actually TWO STAGES of the same circuit. The light-lined circuit is the converter stage, and it converts the fine control signal to d. c. The heavy-lined circuit is the amplifier stage, and it amplifies the converter output and feeds it to the amplidyne control fields.

In figure 6–2 the amplifier stage is made up of tubes *V*1 and *V*2 connected for d-c push-pull operation. The input to the amplifier stage comes from the converter stage—it is full-wave rectified d-c. The output of the amplifier stage is fed to the load—the amplidyne control fields. *R*27 and *R*28 are "Thyrite" resistors; their resistances decrease with an increase in voltage. In this way the Thyrite resistors limit the current in the amplidyne control fields. Normally a high voltage will produce excessive current in the control fields. The Thyrite resistors decrease and shunt the excessive current out of the control fields, thus reducing the plate load to *V*1 and *V*2 and thereby limiting the voltage across the control fields.

The action of the amplifier stage is explained by the grid circuits of *V*1 and *V*2. Trace out these grid circuits—you'll go through the bias and coupling circuits for each tube.

For *V*1—grid, *R*18, *R*25, *R*22, and cathode.

For *V*2—grid, *R*19, *R*20, *R*25, *R*22, and cathode.

The polarity of *R*25 adds a positive voltage to the two grids.

Refer to figure 6–2 and trace the input signal to *V*1 and *V*2. *V*1 gets its signal across *R*18. The *V*1 signal is developed by the I_a from the converter stage. *V*2 gets its signal across *R*20 and part of *R*19. The *V*2 signal is developed by the I_b from the converter stage. Both signals are smooth d. c. They are FILTERED by *C*8 and *C*9.

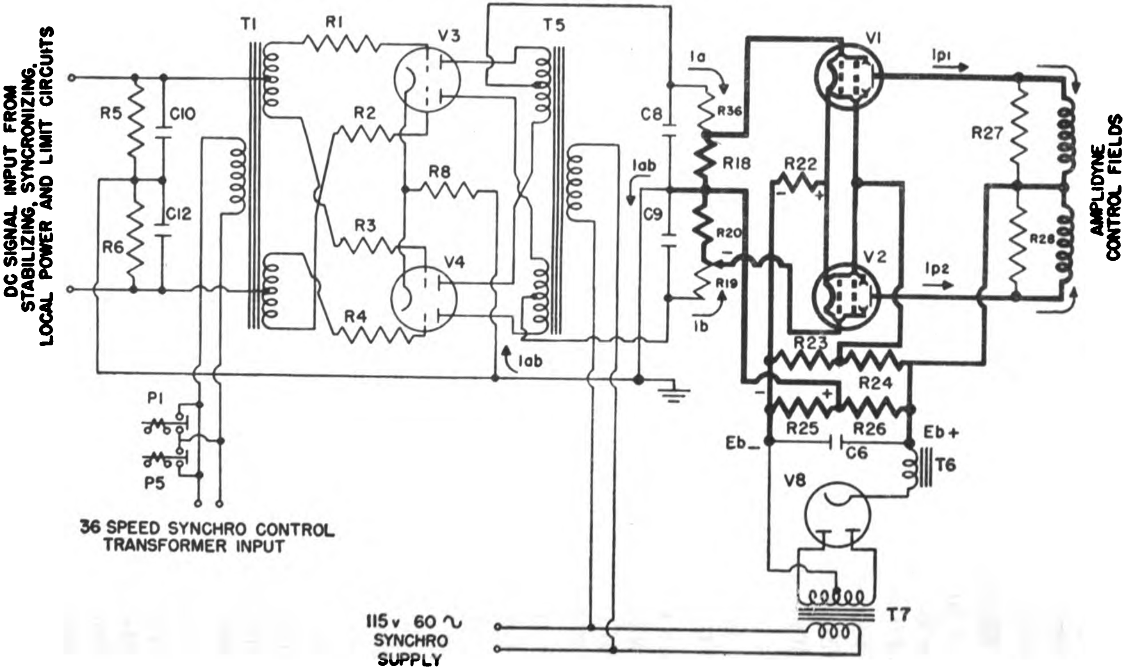


Figure 6-2.—Converter-amplifier circuit.

AMPLIFIER CIRCUIT—NO-SIGNAL

Referring again to figure 6–2, for NO-SIGNAL at $T1$, currents I_a and I_b are equal. This makes the signal at $R18$ equal to the signal at $R19$, $R20$. Now here is the important point—the two signal voltages are just about canceled by the positive voltage at $R25$. Check this canceling action of $R25$ in figure 6–2.

When the two signal voltages and the $R25$ voltage cancel each other, the only voltage remaining on the grids of $V1$ and $V2$ is the voltage across $R22$. $R22$ is really an R_k, and it biases $V1$ and $V2$ at the midpoint of their I_pE_g curves. Since $R22$ is in both grid circuits, $V1$ and $V2$ are biased EQUALLY; and with equal bias, they have equal plate current. Current I_{p1} is fed to one amplidyne control field, and I_{p2} is fed to the other amplidyne control field. The two control fields are balanced by the equal plate current, and the amplidyne output is zero. If there is no signal input at $T1$—balanced amplidyne control fields—no amplidyne output.

AMPLIFIER CIRCUIT—SIGNAL

Now let's suppose a signal is applied at $T1$ which decreases I_a and increases I_b. The decreased I_a lowers the negative voltage across $R18$, and the positive $R25$ voltage makes the grid of $V1$ less negative. I_{p1} INCREASES, the top amplidyne control field becomes stronger, and the amplidyne output drives the mount in right train.

At the same time the increased I_b raises the negative voltage across $R19$, $R20$ and makes the grid of $V2$ more negative and I_{p2} decreases. This action weakens the bottom amplidyne control field and aids the amplidyne output to drive the mount in right train.

The combined $V1$, $V2$ action acts like push-pull. The increased $V1$ current pushes, and the decreased $V2$ current pulls.

For a signal of the opposite phase at $T1$, I_{p2} will increase and I_{p1} will decrease. The amplidyne output will then drive the mount in left train.

Notice that the amplidyne output is a result of unbalancing

I_{p1} and I_{p2}. The decrease in one plate current is equally as important as the increase in the other plate current.

To review the conditions for NO-SIGNAL input, *V*1 and *V*2 outputs are balanced. With the outputs balanced, the two amplidyne control fields cancel each other and there is no amplidyne output.

For conditions WITH AN INPUT SIGNAL, *V*1 and *V*2 outputs are unbalanced. With the outputs unbalanced, one amplidyne control field is stronger and the other is weaker. This results in an amplidyne output with a polarity corresponding to the signal.

BIASING-CIRCUIT DETAILS

You are probably wondering why the *R*25 voltage is needed. It seems that *R*25 only cancels the two no-signal voltages at *R*18, and *R*19, *R*20. The reason for *R*25 is that it makes *V*1 and *V*2 operate at the midpoint of their I_pE_g curves. Without *R*25, the negative voltage of *R*22 would add to the negative signal voltages at *R*18 or *R*19, *R*20. This would make the grids of *V*1 and *V*2 highly NEGATIVE. The tubes would be biased NEAR CUTOFF, and I_{p1} and I_{p2} would be small. However, I_{p1} and I_{p2} would still be balanced for no signal.

Without *R*25 a signal would INCREASE the plate current of either *V*1 or *V*2 by a certain amount. Let us say that the plate current of *V*1 increased by a certain amount, then the plate current of *V*2 would decrease but not as much as the increased current in the plate of *V*1, as *V*2 is already too near cutoff for that much of a decrease. In short, the unbalance in the output is less than if the tubes were biased at the midpoints of their curves.

Look at the use of *R*25 this way. By adding a positive voltage to the grids of *V*1 and *V*2, *R*25 biases the tubes at the midpoint of their I_pE_g curves. When the tubes are biased at the midpoint, a signal decreases one plate current by as much as it increases the other. This produces the largest possible unbalance between the two amplidyne control fields.

Here is another detail in the biasing circuit—*R*22 produces a negative feedback. The negative feedback helps to balance the output and to compensate for tube aging.

Finally, don't overlook the *R*19 adjustment, which adjusts the potential on the *V*2 grid so that the no-signal I_{p1} and I_{p2} are EXACTLY EQUAL. When *R*19 is out of adjustment, I_{p1} and I_{p2} are not exactly equal for no-signal. That means an unbalance in the amplidyne control fields, and the mount will creep right or left with a no-signal input.

CONVERTER-PLATE CIRCUIT

Refer to figure 6–1 and notice the inputs to the converter circuit. You will find a-c inputs of one phase or the other and d-c inputs of one polarity or the other.

Now look at figure 6–2 and notice the output of the converter circuit. You will find that the output is always full-wave rectified a-c.

In short, the converter is a FULL-WAVE RECTIFIER, and it is PHASE and POLARITY SENSITIVE. That is, the converter output polarity always corresponds to either the a-c PHASE or the d-c POLARITY of its inputs.

The key to understand the converter action is in the plate circuits. Locate the plate supply voltage in figure 6–3, which comes from the 115-volt a-c synchro rotor supply. Now trace out one of the converter-plate circuits in this figure. Follow the heavy lines for the circuit of *P*1—cathode of *V*3, *P*1, tap 3, tap 4, *R*36, *R*18, *R*8, and back to the cathode of *V*3.

Now trace out the circuits for *P*2, *P*3, and *P*4, paying particular attention to the *T*5 connections. Always trace from cathode to plate to load and back to cathode.

Tracing out the converter-plate circuits shows you two facts. First, the plate supply voltage is a-c. Second, at any instant *P*1 and *P*2 are connected so as to have the SAME POLARITY; likewise, *P*3 and *P*4 are connected to have the same instantaneous polarity.

If you study the circuit carefully, you may wonder why the lower half of *V*3 is connected to operate with the lower half of *V*4, and the upper half of *V*3 to operate with the upper half of *V*4. This arrangement is so that, in the event of

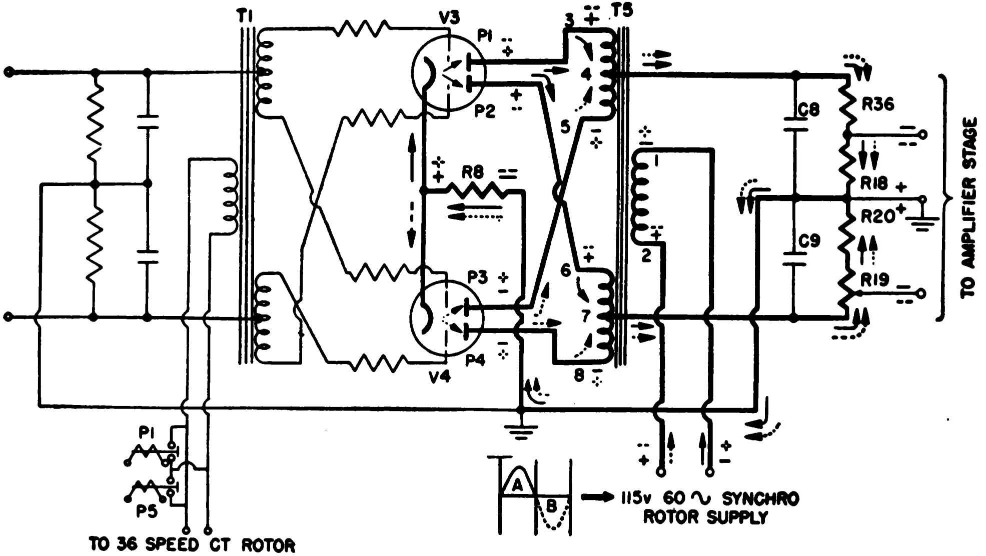


Figure 6-3.—Converter-plate circuit.

failure of either *V*3 or *V*4, the converter will still function—but as a half-wave rectifier rather than as a full-wave rectifier.

PLATE CIRCUIT—NO-SIGNAL

Notice the polarity marking and the current arrows in figure 6–3. The solid markings and solid arrows are for alternation *A* of the a-c plate supply, and the broken markings and broken arrows are for alternation *B*.

Use the arrows to trace out the no-signal plate currents.

For alternation *A*, plates *P*1 and *P*2 are positive, but *P*3 and *P*4 are negative. During this alternation only *P*1 and *P*2 pass current. The *P*1 current is in *R*18 and the *P*2 current is in *R*19, *R*20. Since the *P*1 and *P*2 currents are equal, the *R*18 and *R*19, *R*20 voltages are equal and opposite and that means NO-SIGNAL INPUT to the amplifier stage.

Now trace the plate currents for alternation *B* by following the broken arrows in figure 6–3. Plates *P*1 and *P*2 are negative, and *P*3 and *P*4 are positive. Now only *P*3 and *P*4 pass current. The *P*3 current establishes the *R*18 voltage, and the *P*4 current establishes the *R*19, *R*20 voltage. The two voltages are again equal and opposite; hence, there is no signal input to the amplifier stage.

Notice that *V*3 works on one alternation, and *V*4 works on the other alternation. Therefore, *V*3 and *V*4 make a FULL-WAVE RECTIFIER.

The output of *V*3 and *V*4 is pulsating, but it is filtered by *C*8 and *C*9. The *R*18 and *R*19, *R*20 voltages are smooth d-c.

Thus, for NO-SIGNAL, the *V*3 and *V*4 outputs establish STEADY voltages across *R*18 and *R*19, *R*20. These voltages are EQUAL and OPPOSITE, and there is no input signal to the amplifier stage. With the amplifier stage balanced, the amplidyne control fields are balanced and the amplidyne generator has no output.

CONVERTER-GRID CIRCUITS

The *V*3 and *V*4 grids carry the signals that control the converter-plate currents. Trace these grid circuits to see how the control signals are applied.

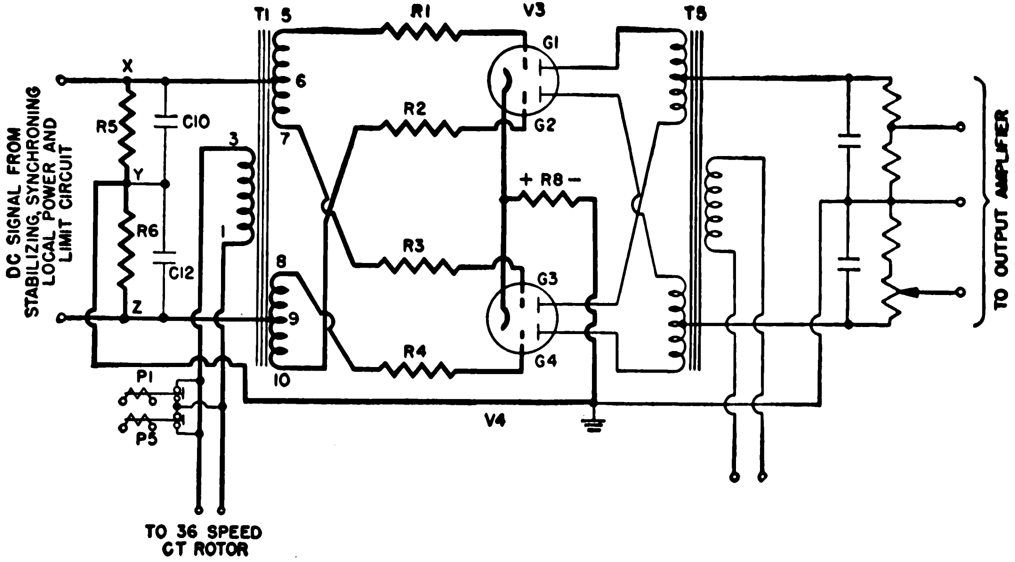


Figure 6-4.—Converter-grid circuits.

Figure 6–4 shows the grid circuits in heavy lines. Here is the *G*1 circuit—grid, *R*1, taps 5 to 6 of *T*1, *R*5, ground, *R*8, and the cathode of *V*3. The *G*2, *G*3, and *G*4 circuits are similar to the *G*1 circuit and may be traced in the same manner.

The FINE-CONTROL SIGNAL is applied across the primary of *T*1 at taps 1 and 3 (fig. 6–4). The signals to all four grids are induced in the secondaries of *T*1. That puts the *G*1 signal between taps 5 and 6, the *G*2 signal between taps 9 and 10, the *G*3 signal between taps 6 and 7, and the *G*4 signal between taps 8 and 9.

The fine signals on the *T*2 secondaries are not the only signals applied to the grids. Notice the relays *P*1 and *P*5. These relays control the other signals. Relay *P*1 shorts out the fine signal for coarse control and *P*5 shorts out the fine signal for local tachometer control.

When the fine signal is shorted out, the grids get a d-c signal from either the coarse C. T. or the tachometer. Both of these d-c signals are applied across *R*5 and *R*6.

The signal voltages across *R*5 and *R*6 either aid or oppose the bias at *R*8. For example, suppose a signal voltage makes point *x* more positive than point *z*. This signal voltage OPPOSES the bias for *G*1 and *G*3; hence *G*1 and *G*3 become LESS negative. At the same time the signal voltage AIDS the bias for *G*2 and *G*4; hence *G*2 and *G*4 become MORE negative.

The *T*2 secondaries are conductors for the d-c signals as they develop practically NO VOLTAGE when they carry d. c.

Let's review the converter grid circuits for all three signals: first, the FINE control, where an a-c signal is developed across *T*2 secondaries; second, the COARSE control in which the fine-control signal is shorted out by *P*1 and the coarse signal is developed across *R*5 and *R*6; and third, the LOCAL TACHOMETER control where the fine-control signal is shorted out by *P*5, and the local tachometer signal is across *R*5 and *R*6.

FINE SIGNAL—IN-PHASE

An in-phase signal is a fine signal across *T*1 that is in phase with the plate supply voltage. The in-phase signal produces right train.

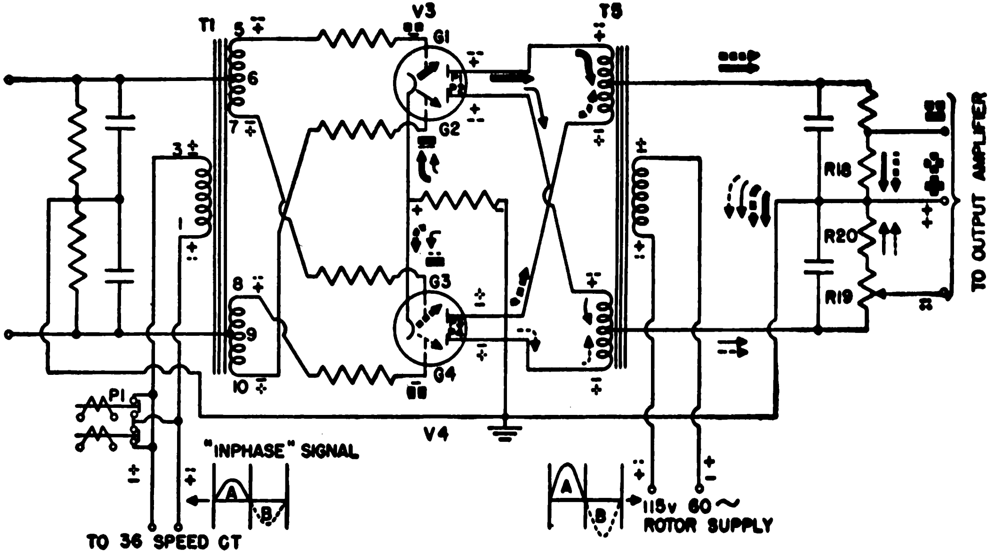


Figure 6-5.—In-phase signal.

The polarities and current directions for an in-phase signal are shown in figure 6–5. The solid signs and arrows are for alternation *A*; the broken signs and arrows are for alternation *B*.

Refer to figure 6–5 and trace the operation for alternation *A* of the in-phase signal. The two plates of *V*3 are positive. The signal makes *G*1 less negative and *G*2 more negative, and the change in grid potentials unbalances the plate currents. The *P*1 current increases and the *P*2 current decreases.

These unbalanced plate currents set up the signal input to the amplifier stage. The *P*1 current increases the voltage developed across *R*18, and the *P*2 current decreases the voltage developed across *R*19, *R*20. The amplidyne control fields are unbalanced, and the amplidyne output drives the mount in right train. Both *P*3 and *P*4 are negative for alternation *A*.

Now trace the operation for alternation *B*. The two plates of *V*4 are now positive, but the two plates of *V*3 are negative. This means that only *V*4 is able to pass current. For alternation *B* of the signal, *G*3 is less negative and *G*4 is more negative, so the signal increases the *P*3 current and decreases the *P*4 current.

The *P*3 current increases the voltage across *R*18 and the *P*4 current decreases the voltage across *R*19, *R*20. The result is the same input to the amplifier stage as with alternation *A* and the same unbalance in the amplidyne control fields. The mount trains right.

Review the action for an in-phase signal. Notice that *P*1 and *P*3 do all the work for an in-phase signal. *P*1 works for alternation *A* and *P*3 for alternation *B*. Both *P*1 and *P*3 currents increase the *R*18 voltage, and *P*2 and *P*4 currents decrease the *R*19, *R*20 voltage. Finally, the unbalance between the *R*18 and *R*19, *R*20 voltages is amplified so that it unbalances the amplidyne output and produces right train.

FINE SIGNAL—OUT-OF-PHASE

An out-of-phase signal is a fine signal across *T*1 that is 180° out-of-phase with the plate supply voltage. The out-of-phase signal produces left train.

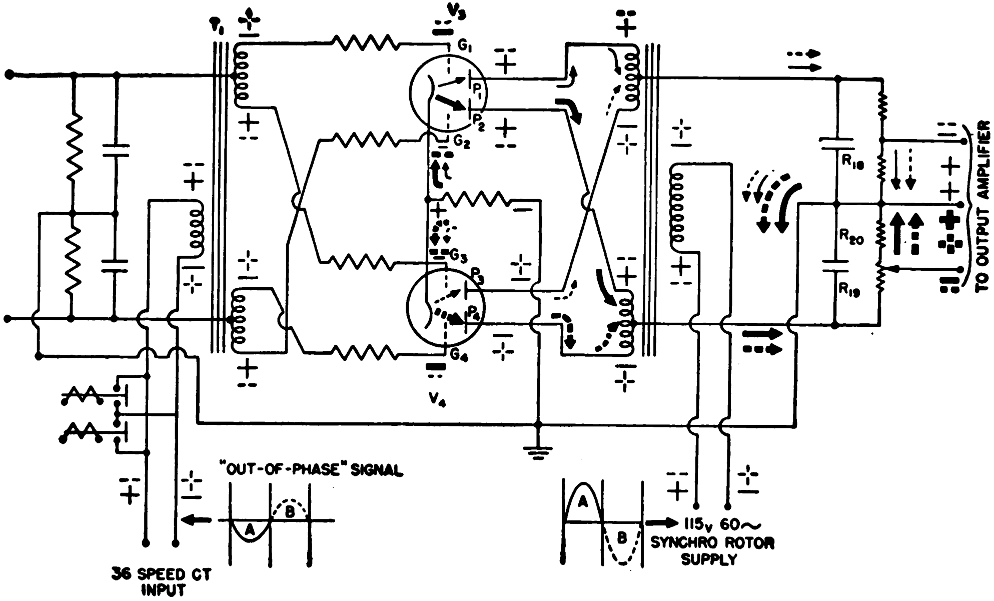


Figure 6-6.—Out-of-phase signal.

Follow the out-of-phase signal through the converter circuit in figure 6–6. The circuit is labeled with solid signs and arrows for alternation *A*, and broken signs and arrows for alternation *B*.

Notice the plate currents for the two alternations. For alternation *A*, the *P*2 current increases while the *P*1 current decreases. For alternations *B*, the *P*4 current increases while the *P*3 current decreases.

The *P*2 and *P*4 currents increase the *R*19, *R*20 voltage, and at the same time *P*1 and *P*3 currents decrease the *R*18 voltage. This unbalances the amplidyne control fields so that the amplidyne output produces left train.

D-C SIGNAL—RIGHT-TRAIN

The converter stage gets d-c signal inputs from two sources, the coarse C. T. and the local tachometer. In addition to the d-c signals, the converter stage also receives the stabilizing voltages as inputs. Actually the stabilizing voltages alternate according to the hunt or jitter of the mount. These alternations have a LOW frequency, lower than 60-cycle. Therefore, the stabilizing voltages can be considered d.c.

The action in the converter stage depends only on the POLARITY of the d-c signal, regardless of where the signal originates. That means you can understand the action for any d-c signal merely by following one signal through the converter stage.

The action for a right-train d-c signal is shown in figure 6–7. The signal voltage is developed across *R*5 and *R*6. Notice the polarities—the top of *R*6 is positive and the bottom is negative.

Now the voltage across *R*5 opposes the negative bias at *R*8. This makes *G*1 and *G*2 go LESS negative, and at the same time the voltage across *R*6 AIDS the negative bias at *R*8. This makes *G*2 and *G*4 MORE negative.

On the first alternation of the supply *P*1 passes a large current and *P*2 passes very little. On the second alternation of the supply, *P*3 passes a large current and *P*4 very little. The result is that *P*1 and *P*3 currents INCREASE the

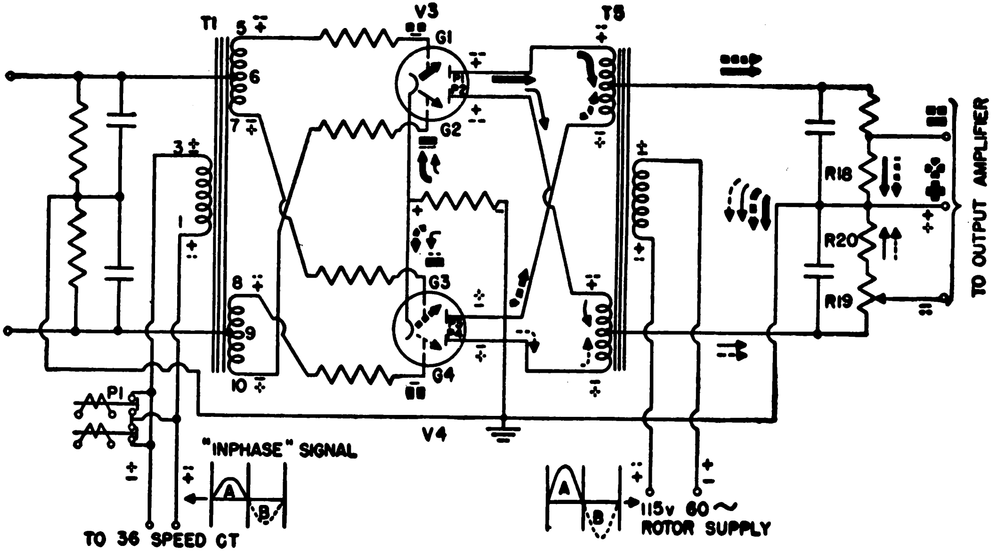


Figure 6-5.—In-phase signal.

The polarities and current directions for an in-phase signal are shown in figure 6–5. The solid signs and arrows are for alternation *A*; the broken signs and arrows are for alternation *B*.

Refer to figure 6–5 and trace the operation for alternation *A* of the in-phase signal. The two plates of *V*3 are positive. The signal makes *G*1 less negative and *G*2 more negative, and the change in grid potentials unbalances the plate currents. The *P*1 current increases and the *P*2 current decreases.

These unbalanced plate currents set up the signal input to the amplifier stage. The *P*1 current increases the voltage developed across *R*18, and the *P*2 current decreases the voltage developed across *R*19, *R*20. The amplidyne control fields are unbalanced, and the amplidyne output drives the mount in right train. Both *P*3 and *P*4 are negative for alternation *A*.

Now trace the operation for alternation *B*. The two plates of *V*4 are now positive, but the two plates of *V*3 are negative. This means that only *V*4 is able to pass current. For alternation *B* of the signal, *G*3 is less negative and *G*4 is more negative, so the signal increases the *P*3 current and decreases the *P*4 current.

The *P*3 current increases the voltage across *R*18 and the *P*4 current decreases the voltage across *R*19, *R*20. The result is the same input to the amplifier stage as with alternation *A* and the same unbalance in the amplidyne control fields. The mount trains right.

Review the action for an in-phase signal. Notice that *P*1 and *P*3 do all the work for an in-phase signal. *P*1 works for alternation *A* and *P*3 for alternation *B*. Both *P*1 and *P*3 currents increase the *R*18 voltage, and *P*2 and *P*4 currents decrease the *R*19, *R*20 voltage. Finally, the unbalance between the *R*18 and *R*19, *R*20 voltages is amplified so that it unbalances the amplidyne output and produces right train.

FINE SIGNAL—OUT-OF-PHASE

An out-of-phase signal is a fine signal across *T*1 that is 180° out-of-phase with the plate supply voltage. The out-of-phase signal produces left train.

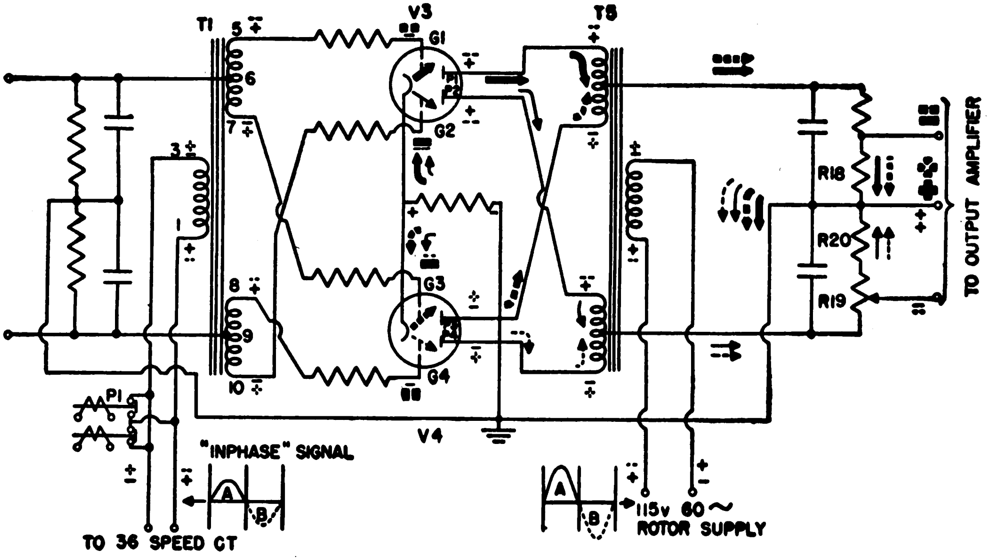


Figure 6-5.—In-phase signal.

The polarities and current directions for an in-phase signal are shown in figure 6–5. The solid signs and arrows are for alternation *A*; the broken signs and arrows are for alternation *B*.

Refer to figure 6–5 and trace the operation for alternation *A* of the in-phase signal. The two plates of *V*3 are positive. The signal makes *G*1 less negative and *G*2 more negative, and the change in grid potentials unbalances the plate currents. The *P*1 current increases and the *P*2 current decreases.

These unbalanced plate currents set up the signal input to the amplifier stage. The *P*1 current increases the voltage developed across *R*18, and the *P*2 current decreases the voltage developed across *R*19, *R*20. The amplidyne control fields are unbalanced, and the amplidyne output drives the mount in right train. Both *P*3 and *P*4 are negative for alternation *A*.

Now trace the operation for alternation *B*. The two plates of *V*4 are now positive, but the two plates of *V*3 are negative. This means that only *V*4 is able to pass current. For alternation *B* of the signal, *G*3 is less negative and *G*4 is more negative, so the signal increases the *P*3 current and decreases the *P*4 current.

The *P*3 current increases the voltage across *R*18 and the *P*4 current decreases the voltage across *R*19, *R*20. The result is the same input to the amplifier stage as with alternation *A* and the same unbalance in the amplidyne control fields. The mount trains right.

Review the action for an in-phase signal. Notice that *P*1 and *P*3 do all the work for an in-phase signal. *P*1 works for alternation *A* and *P*3 for alternation *B*. Both *P*1 and *P*3 currents increase the *R*18 voltage, and *P*2 and *P*4 currents decrease the *R*19, *R*20 voltage. Finally, the unbalance between the *R*18 and *R*19, *R*20 voltages is amplified so that it unbalances the amplidyne output and produces right train.

FINE SIGNAL—OUT-OF-PHASE

An out-of-phase signal is a fine signal across *T*1 that is 180° out-of-phase with the plate supply voltage. The out-of-phase signal produces left train.

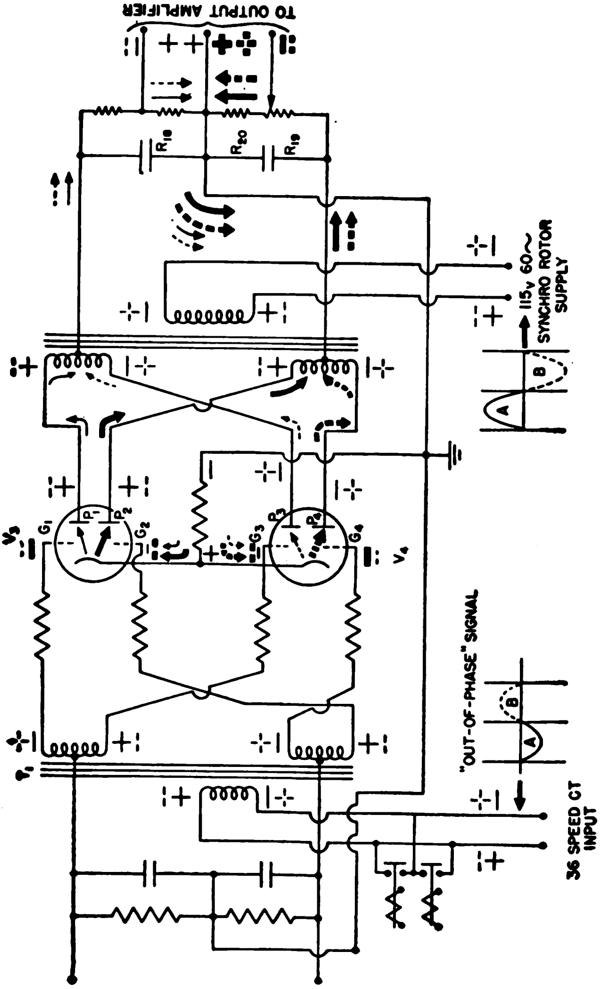


Figure 6-6.—Out-of-phase signal.

Follow the out-of-phase signal through the converter circuit in figure 6–6. The circuit is labeled with solid signs and arrows for alternation *A*, and broken signs and arrows for alternation *B*.

Notice the plate currents for the two alternations. For alternation *A*, the *P*2 current increases while the *P*1 current decreases. For alternations *B*, the *P*4 current increases while the *P*3 current decreases.

The *P*2 and *P*4 currents increase the *R*19, *R*20 voltage, and at the same time *P*1 and *P*3 currents decrease the *R*18 voltage. This unbalances the amplidyne control fields so that the amplidyne output produces left train.

D-C SIGNAL—RIGHT-TRAIN

The converter stage gets d-c signal inputs from two sources, the coarse C. T. and the local tachometer. In addition to the d-c signals, the converter stage also receives the stabilizing voltages as inputs. Actually the stabilizing voltages alternate according to the hunt or jitter of the mount. These alternations have a LOW frequency, lower than 60-cycle. Therefore, the stabilizing voltages can be considered d.c.

The action in the converter stage depends only on the POLARITY of the d-c signal, regardless of where the signal originates. That means you can understand the action for any d-c signal merely by following one signal through the converter stage.

The action for a right-train d-c signal is shown in figure 6–7. The signal voltage is developed across *R*5 and *R*6. Notice the polarities—the top of *R*6 is positive and the bottom is negative.

Now the voltage across *R*5 opposes the negative bias at *R*8. This makes *G*1 and *G*2 go LESS negative, and at the same time the voltage across *R*6 AIDS the negative bias at *R*8. This makes *G*2 and *G*4 MORE negative.

On the first alternation of the supply *P*1 passes a large current and *P*2 passes very little. On the second alternation of the supply, *P*3 passes a large current and *P*4 very little. The result is that *P*1 and *P*3 currents INCREASE the

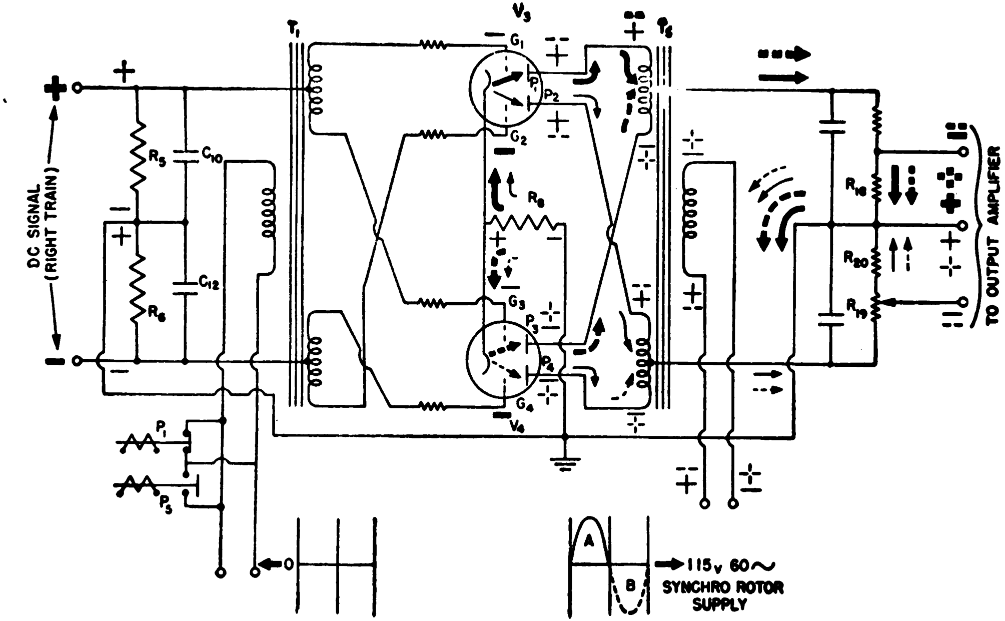


Figure 6-7.—D-c signal, right-train.

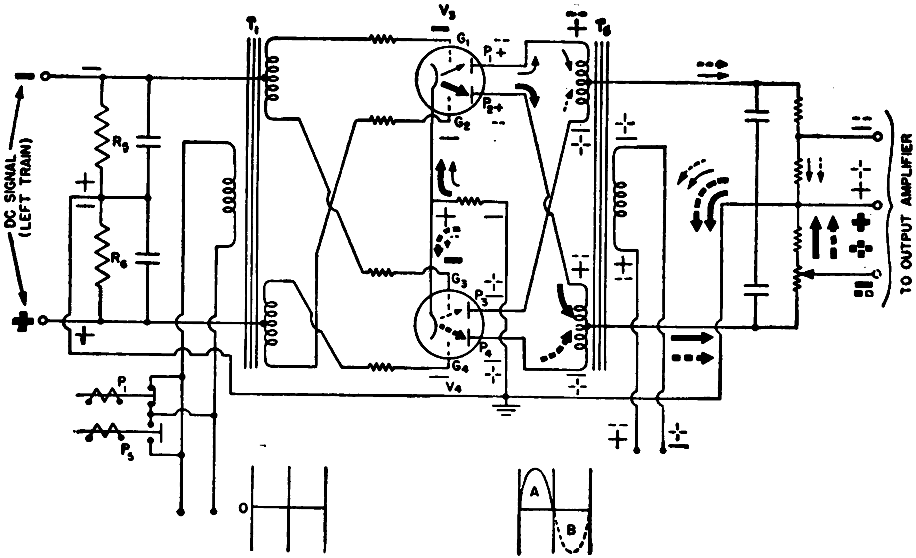


Figure 6-8.—D-c signal, left-train.

*R*18 voltage, and the *P*2 and *P*4 currents DECREASE the *R*19, *R*20 voltage. The amplidyne output produces right train.

D-C SIGNAL—LEFT-TRAIN

Figure 6–8 shows all the polarities and current directions for a left-train d-c signal. Trace it out for both power supply alternations.

The action at the converter stage with three different signal inputs has been discussed. That is the proper way to consider the action for the three signals, as only one signal is fed to the converter at any one time. But it is not the right way to consider the action for the stabilizing voltages because all three of the stabilizing voltages are present at the same time.

In addition, the stabilizing voltages are combined with the fine-control signal voltage at the grid circuits of *V*3 and *V*4. Thus, the total grid voltage is the RESULT of combining the signal voltage with the stabilizing voltages.

To make it easier to trace circuits and to accomplish troubleshooting, always consider the stabilizing voltages separately.

STABILIZING

Stabilizing means keeping the mount steady in correspondence. To keep it steady, you must remove the hunting and jitter.

Hunting occurs in fine control when the mount overdrives correspondence. The overdrive reverses the signal, and the mount reverses to get back into correspondence.

Jitter is a kind of hunt. Jitter occurs at or very near correspondence. The jitter reversals are much faster than those that occur during hunting.

Both hunting and jitter are removed by the stabilizing voltages.

Stabilizing Voltages

There are THREE stabilizing voltages—one from the stabilizing generator, a second from the compensating field of the amplidyne, and the third from the amplidyne quadrature winding. Each of these sources is shown in figure 6–9.

Figure 6–9 shows that all three stabilizing voltages are fed back to combine with the fine-signal input at the converter stage.

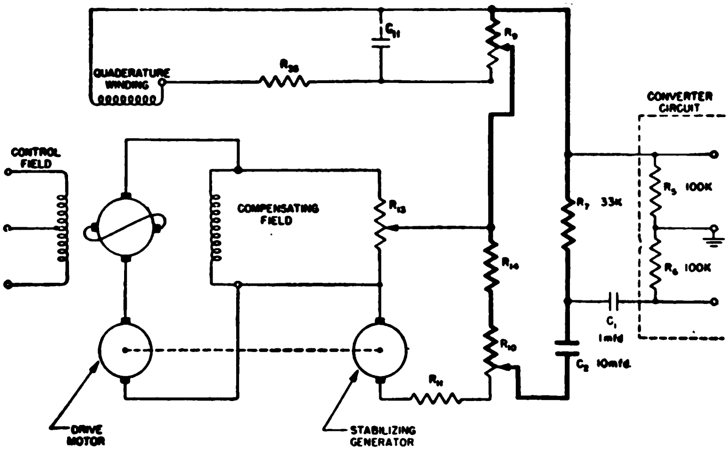


Figure 6–9.—Stabilizing voltages.

The stabilizing generator is a d-c generator geared to the mount. This makes the generator output proportional to the mount's speed. The output polarity depends upon the mount's direction. For these reasons the output of the stabilizing generator can be called the SPEED FEEDBACK. This feedback is effective only for high mount speeds.

The compensating field carries the drive motor current. Therefore, the voltage across the compensating field is proportional to the current drawn by the drive motor. For this reason the voltage across the compensating field can be called CURRENT FEEDBACK. This feedback is most effective when the drive motor draws heavy currents, for example, at starts and reversals.

The quadrature winding is threaded by the quadrature flux. This winding is CUT by the quadrature flux only when the flux changes strength. This happens only when the load on the amplidyne CHANGES. Thus, the voltage induced in the quadrature winding is proportional to the RATE of load change, and the frequency of the voltage in the quadrature winding is equal to the frequency of the quadrature flux changes.

The rate of load change is greatest when the mount is reversing fastest during jitter. For this reason the voltage in the quadrature winding can be called JITTER FEEDBACK.

COMBINING THE STABILIZING VOLTAGE

The heavy-lined loop in figure 6–9 combines the three stabilizing voltages by adding them across *R*9, *R*14, and *R*10.

The jitter feedback voltage from the quadrature winding is developed across *R*9. The combination *R*35, *C*11 acts as a low-pass filter for this voltage. This filter reduces the HIGH frequencies caused by commutation at the amplidyne but passes the relatively low-frequency jitter voltages.

The current feedback voltage from the compensating field is developed across *R*13, and only a part of this stabilizing voltage is tapped off. The voltage tapped off at *R*13 is ADDED to the speed feedback voltage from the stabilizing generator. The current feedback and the speed feedback is ADDED across *R*14 and *R*10.

The feedback adjustments are *R*9, *R*13, and *R*10. *R*9 controls the amount of jitter feedback, while *R*13 controls the amount of current feedback, and *R*10 controls the amount of current-speed feedback. Since these three potentiometers are adjusted at the factory to allow just the right amount of each one of the stabilizing voltages to enter the amplifier, they need not be adjusted unless a new amplifier is installed.

The combined stabilizing voltages are across *R*7 and *C*2. The *R*7 voltage goes to the converter circuit and adds to the fine signal across *R*5 and *R*6.

Stabilizing Voltage Filter

*R*7 and *C*2 make up a high-pass filter. The lower frequency voltages are across *C*2, and the higher frequency voltages are across *R*7. Since only that voltage which appears across *R*7 can reach the converter and because of the further reduction in low-frequency energy due to the small value of *C*1, only the high-frequency stabilizing components of the signal voltage will get through to the converter. Thus slow movements of the mount are not included in the stabilizing inputs.

Here is an example of how the high-pass filter works. Roll-and-pitch-correction signals set up low-frequency stabilizing voltages. These voltages are not needed to stabilize the mount. In fact, the low-frequency voltages would DECREASE the accuracy of the mount.

These low-frequency voltages are very large across *C*2 and very small across *R*7. The low-frequency voltages do not get through to the converter; they are blocked by the high-pass filter.

Here is a complete explanation of the action of *R*7, *C*2. The reactance of *C*2 DECREASES with the INCREASED frequency; as the reactance of *C*2 decreases, the voltage across *C*2 decreases. On the other hand, the reactance of *C*2 INCREASES as the frequency DECREASES; and as the reactance increases, the voltage across *C*2 increases.

Now try a low-frequency voltage across *C*2 and *R*7. The high reactance of *C*2 uses up most of the voltage and very little is across *R*7. That means very little voltage gets to the converter. This is what happens to the low-frequency voltages set up by the slow movements (roll and pitch) of the mount.

Now try a high-frequency voltage across *C*2 and *R*7. The low reactance of *C*2 uses up very little of the voltage; most of it is across *R*7. That means most of the voltage gets to the converter. This is what happens to the high-frequency voltages set up by hunting and jitter.

Imagine what would happen at *C*2 if the stabilizing voltages were smooth d. c. D. c. has a frequency of zero, so all the voltage would be across *C*2. Thus, the high-pass filter BLOCKS all smooth d. c. from the converter.

Finally, the voltage across *R*7 is always phased to oppose the fine control signal. In other words, the *R*7 voltage opposes the voltage across *R*5 and *R*6. This makes the stabilizing voltages act exactly like negative feedback.

SYNCHRONIZING CIRCUIT

Refer again to figure 6–1 and locate the synchronizing local power and limit circuits block. This block actually contains only one circuit, but it is easier to understand this circuit if it is broken down into three sub-circuits. Each one of the three circuits will then show only one kind of operation: synchronizing control, local power control, or limit control.

There are two inputs to this block, as shown in figure 6–1: the coarse control signal and the signal from the local tachometer. These two inputs are controlled by the selector switch which allows only one input into the circuit at any one time.

All outputs of block *A* go directly into the stabilizing circuit, as shown in figure 6–1.

The synchronizing circuit is shown by the heavy lines in figure 6–10.

Now locate the *P*1 relay contacts in figure 6–10. These two sets of contacts are energized by the coarse control signal when the error is 2.5 degrees or more. When the two sets of contacts close, one shorts-out the fine control signal as shown in figure 6–8, and the other completes the coarse control circuit. This puts the mount in coarse control.

The two tubes used to rectify the coarse control signal (*V*5 and *V*6) are shown in figure 6–10. *V*5 rectifies the left train, and *V*6 rectifies the right train signal. The output of both tubes is across *R*39.

Trace the circuit from *R*39 to *R*5 and *R*6. This shows you that the *R*39 voltage becomes part of the input to the converter stage. It also shows that the *R*39 voltage is combined with the stabilizing voltages across *R*10, *R*14, and *R*9. The stabilizing tachometer acts as a governor for high synchronizing speeds because it opposes the *R*39 voltage.

The other two stabilizing voltages are not effective since the quadrature winding and the compensating winding voltages are practically zero in coarse control. Coarse control means 2.5 degrees out of correspondence, and there is no hunting or jitter with that much error.

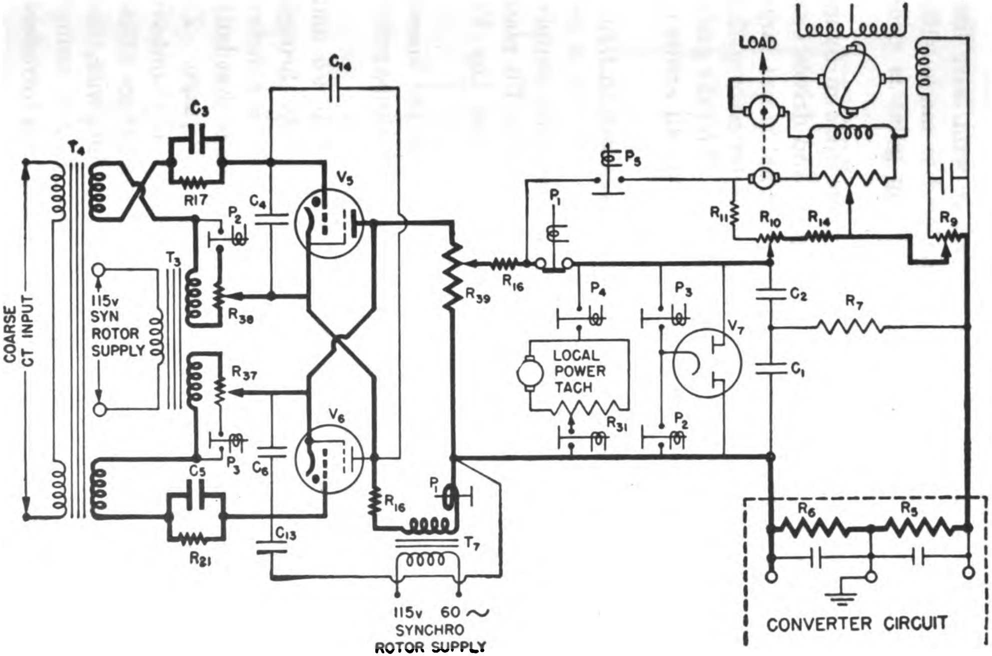


Figure 6–10.—Synchronizing control circuits.

Synchronizing Circuit—No Signal

*V*5 and *V*6 are thyratrons (gas-filled, grid-controlled rectifiers). The two things you must always remember about the firing point of the thyratron is that it WILL "fire" only when its plate is positive and that it WILL NOT fire, even when the plate is positive, if the grid is made sufficiently negative. Thus the thyratron firing point is grid-controlled.

Now look at the grid circuits of the thyratrons in figure 6–10. The coarse signal is fed to the grids and drives ONE of the grids LESS NEGATIVE. The coarse signal is not large enough to cause either *V*5 or *V*6 to fire until an error of 2.5 degrees is reached because of the a-c bias from *T*3 on the grids. In short, *V*5 and *V*6 block the coarse signal for all errors of less than 2.5 degrees.

The synchronizing circuit for no signal is shown in figure 6–11. Notice the plate supply for *V*5 and *V*6. It is a-c from *T*7, and *T*7 is energized from the synchro rotor supply.

Check the plate polarities in figure 6–11. The *V*6 plate is positive for alternation *A* of the supply, and the *V*5 plate is positive for alternation *B* of the supply.

In the grid circuits for *V*5 and *V*6 both grids are biased by the a-c voltage of *T*3, and *T*3 is energized from the synchro rotor supply just as *T*7 is.

Let's review the plate and grid voltages. The *V*5 and *V*6 PLATES are energized by the synchro rotor supply through *T*7, and the *V*5 and *V*6 GRIDS are biased by the synchro rotor supply through *T*3. The important thing is that both the plates and the grids carry the SAME a-c voltage. *T*3 is phased so that the GRID voltages are exactly 180° out-of-phase with the PLATE voltages. The *V*5 GRID swings NEGATIVE when the *V*5 PLATE swings POSITIVE. Likewise, the *V*6 GRID swings NEGATIVE when the *V*6 PLATE swings POSITIVE. In short, for NO SIGNAL the a-c grid bias furnished by *T*3 BLOCKS both *V*5 and *V*6.

The most important thing in figure 6–11 is the BIAS SYSTEM. Be sure you understand how the bias blocks *V*5 and *V*6 for no signal. To be sure, trace out the biasing system, using

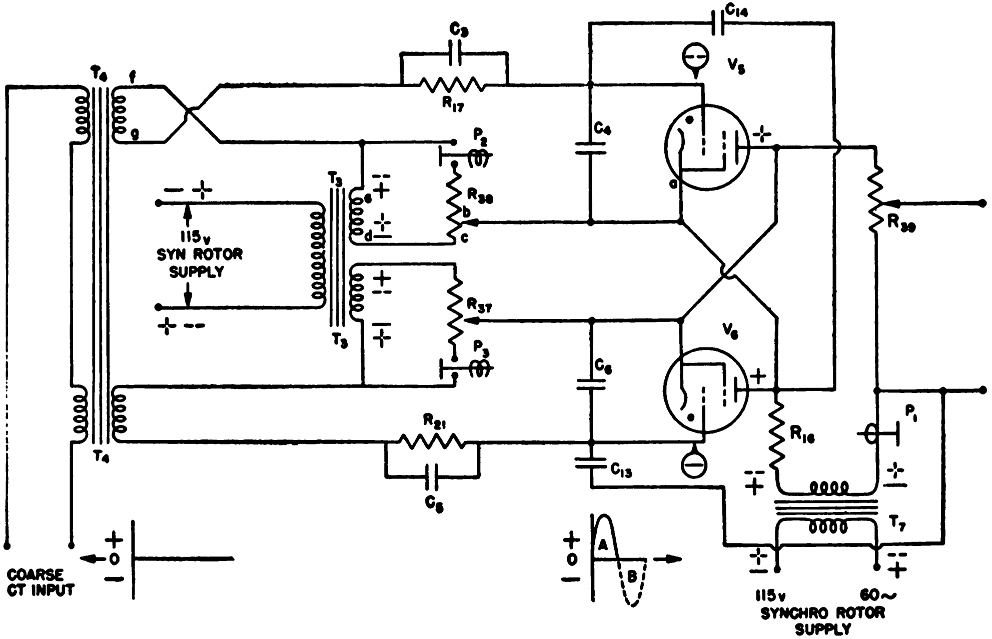


Figure 6-11.—Synchronizing circuit, no signal.

the grid circuit of *V*5 as an example. Trace it out by following these points in figure 6–11—*a*, *b*, *c*, *d*, *e*, *f*, *g*, *R*17, and grid. Notice the polarity marking at the *V*5 plate, and then notice the polarity at points *d* and *e*. Compare plate and grid polarities, and you will know why *V*5 is blocked for no signal.

Tracing out the *V*5 grid circuit brings up some other items in the grid circuits. First, note *P*2 and *P*3. These two relays are part of the LIMIT CONTROL. They are always OPEN for normal operation; therefore, *P*2 and *P*3 can be ignored for synchronizing operation.

Second, there is the GRID LEAK BIAS NETWORK, *R*17, *C*3 and *R*21, *C*5. *C*3 and *C*5 CHARGE on large POSITIVE signal peaks and put a NEGATIVE BIAS on the *V*5 and *V*6 grids. This additional negative bias opposes the large positive signal peaks. Thus, the grid leak bias networks prevent excessive grid current and signal overload.

Finally, note *C*4 and *C*6 in figure 6–11. These two condensers are PHASE TRIMMERS and are connected between the cathodes and grids so that they adjust the phase of the grid voltage. *C*4 and *C*6 are selected to make the grid voltage exactly 180° out-of-phase with the plate voltage.

Synchronizing Circuit—Right-Train Signal

The right-train signal comes from the coarse C. T. and it is fed to the synchronizing circuit at *T*4. You can see the action of the right-train signal in figure 6–12 if you trace the synchronizing circuit. Notice that the circuit is polarized for an IN-PHASE signal.

During alternation *A* of this circuit the *V*6 plate is POSITIVE and the *V*5 plate is NEGATIVE. This means that *V*6 is ABLE TO CONDUCT, but *V*5 CANNOT CONDUCT. Check this by following the solid arrows and polarities.

Further, in alternation *A* the *V*5 GRID is driven MORE negative by the *T*4 signal voltage, but the *V*6 GRID is driven LESS negative by the *T*4 signal voltage, and the *T*4 signal is cancelling some of the *T*3 bias. This means that *V*6 with ITS POSITIVE PLATE and LESS NEGATIVE GRID CONDUCTS CURRENT.

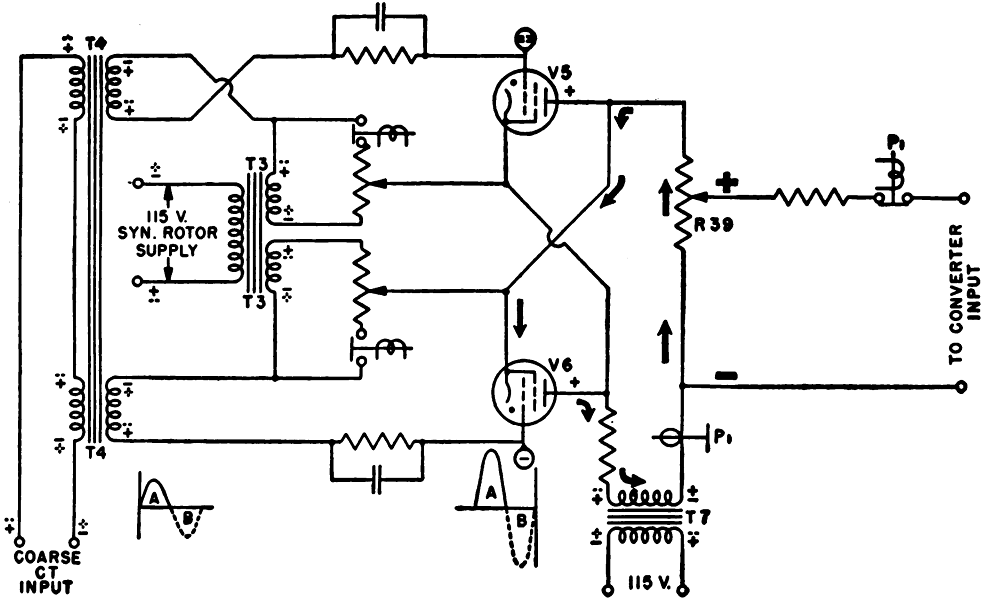


Figure 6–12.—Synchronizing circuit, right-train signal.

Trace the *V*6 current by following the solid arrows in figure 6–12. The current flows through *T*7, *P*1, and *R*39. In *P*1 the *V*6 current closes the contacts and shorts-out the fine signal, and in *R*39 the *V*6 current develops a pulsating d-c voltage.

Follow the broken arrows and polarities and see what happens during alternation *B*. Here the *V*5 plate is positive, but the *V*5 grid is driven MORE NEGATIVE by the signal at *T*4. *V*5 does not conduct; hence, no current passes through *R*39. Thus only *V*6 conducts current through *R*39 on an IN-PHASE SIGNAL.

The *R*39 voltage is the input to the converter stage, and the polarity at *R*39 is correct to produce right train.

Figure 6–13 is the synchronizing circuit POLARIZED for left train. Compare the circuits of figures 6–12 and 6–13 for the right- and left-train signals. Notice that the left-train signal phase is exactly OPPOSITE to the right-train signal phase.

During alternation *A* the *V*6 plate is positive, but the *V*6 grid is driven more negative by the signal at *T*4. Consequently *V*6 does not conduct during alternation *A*. At the same time the plate of *V*5 is negative, so *V*5 does not conduct during alternation *A*.

Use the broken arrows and signs in figure 6–13 to trace out the circuit for alternation *B*. The *V*6 plate is negative, and *V*6 does not conduct. The *V*5 plate is positive, and the *V*5 grid is driven LESS negative by the signal at *T*4. Consequently *V*5 fires, and the *V*5 current follows the broken arrows.

Trace the *V*5 current and notice that it closes P1 just as the *V*6 current did. The *V*5 current sets up a pulsating d-c voltage across *R*39 just as the *V*6 current did, but the *R*39 voltage developed by the *V*5 current is OPPOSITE in polarity to the *R*39 voltage developed by the *V*6 current. The *R*39 voltage developed by the *V*5 current has the correct polarity to produce left train.

Here is the action of *V*5, *V*6. Either tube will fire if its plate is made positive by the supply voltage and its grid is made less negative by the signal at the SAME TIME. This

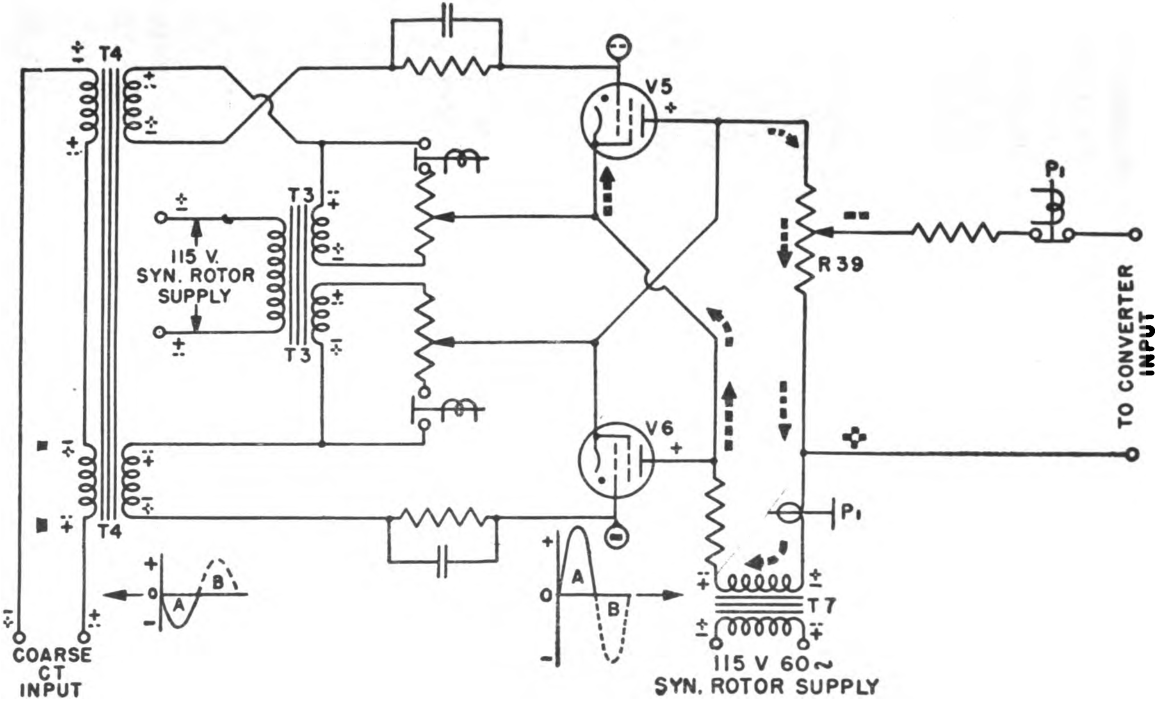


Figure 6–13.—Synchronizing circuit, left-train.

happens to *V*6 for RIGHT TRAIN and to *V*5 for LEFT TRAIN. The *V*6 current sets up a voltage at *R*39 for right train, and the *V*5 current sets up a voltage at *R*39 for left train.

LOCAL CONTROL

You have now covered the Amplidyne Power Drive, Mk 4, for fine and coarse control. Now look at figure 6–14 and follow the heavy lines for LOCAL POWER of the synchronizing, local power, and limit circuit.

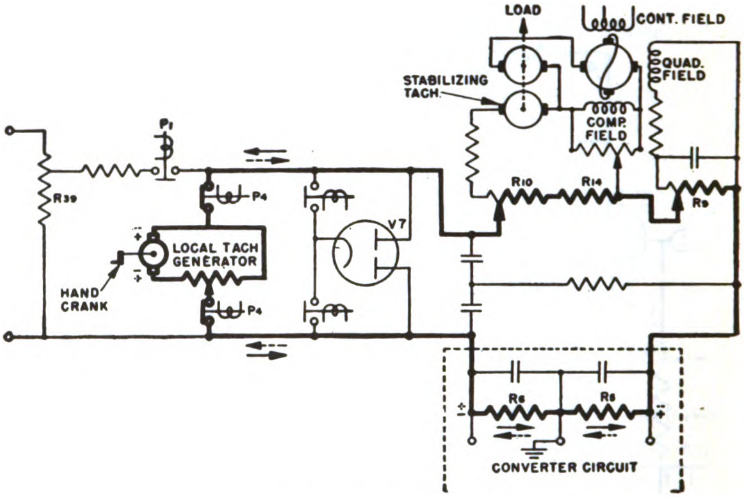


Figure 6–14.—Local power.

Refer to figure 6–14 and locate *P*4. This relay closes the local power circuit. At the time *P*4 closes, the coarse and fine control inputs are cut out by the selector switch. Consequently, the output of the local power tachometer generator and the stabilizing voltages are the only inputs to the converter stage.

For right train the local tachometer is turned in one direction which produces the signal with the SOLID arrows and polarity signs as shown in figure 6–14.

For left train the local tachometer is turned in the opposite direction which produces the signal with the BROKEN arrows and polarity signs as shown in figure 6–14.

The current from the local tachometer produces the voltage across *R*5 and *R*6. This voltage becomes the input to the converter stage. Check the converter input polarities for right and left train. They are the same as the polarities produced by the coarse signal.

Do not overlook the stabilizing voltage across *R*10, *R*14, and *R*9. The only EFFECTIVE stabilizing voltage is the output of the stabilizing tachometer. This voltage OPPOSES the signal from the local power tachometer. Thus, the stabilizing tachometer voltages act as a governor to break the speed when the mount is in local control.

The stabilizing voltage from the compensating field and from the quadrature winding can be ignored because in local control the mount does not hunt or jitter.

LIMIT CIRCUIT—AUTOMATIC CONTROL

Two devices keep the mount from driving into its limits. First, a SPRING BRAKE is released by a cam-operated LIMIT SWITCH. This brake tends to stall the drive motor. Second, the limit circuit cuts out, or greatly reduces, the signal. By cutting out the signal the limit circuit prevents the signal from driving the mount further into the limits.

The complete synchronizing, local power, and limit circuits are shown in figure 6–15. The heavy lines show the circuits that are active when the mount is in the left limit.

Ordinarily the *P*2, *P*3, and *P*5 contacts are held open by their relay coils, but this is what happens when the mount drives into the left limit. The cam-operated switch de-energizes the relay coils, and springs close *P*3 and *P*5. This completes the heavy-lined circuit in figure 6–15.

When *P*5 closes, the fine signal is shorted out. (Check this by finding *P*5 in figure 6–8.) At the same time the *P*5 in figure 6–15 shorts out *R*11 and the heavy-lined part of *R*10. This feeds in ALMOST ALL of the stabilizing tachometer voltage across *R*14 and *R*10. This strong stabilizing tachometer voltage OPPOSES the signal that is driving the mount into the left limit, thus REDUCING the signal.

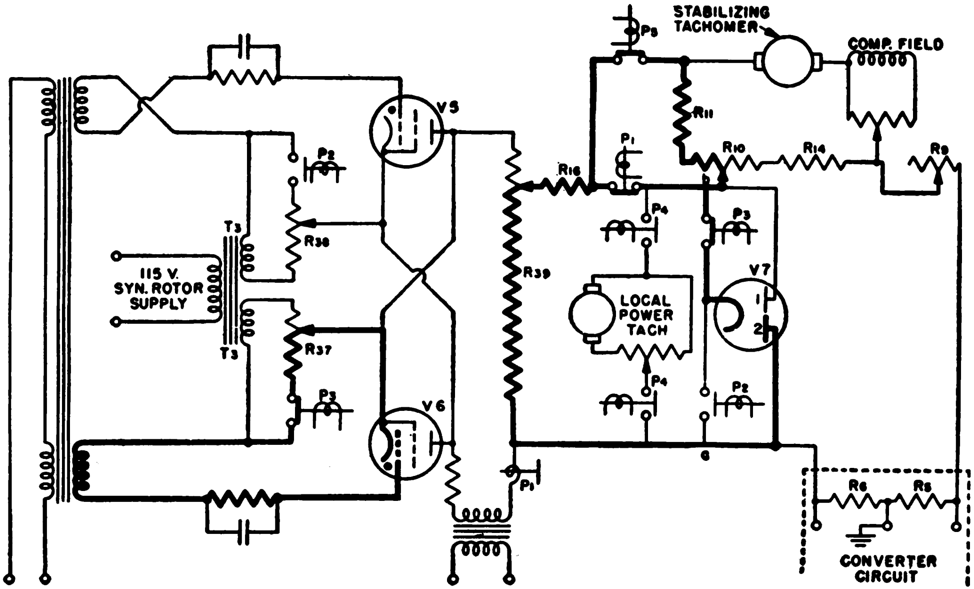


Figure 6-15.—Limit circuit.

At the time *P*5 closes, *P*3 is closed. *P*3 puts *V*7 into the signal circuit and the left-train signal makes point *a* positive and point *b* negative. This means plate 2 is positive with respect to the cathode, so plate 2 of *V*7 conducts current.

To see what the plate current of *V*7 does, trace out the plate circuit—cathode, plate 2, point *a*, *R*16, *P*1, point *b*, *P*3, and back to the cathode.

Tracing this circuit shows that the *V*7 plate current flows through *R*16. This current sets up a voltage across *R*16, and as a result the *R*16 voltage subtracts from the *R*39 voltage. This leaves less voltage across points *a* and *b* and is the same as REDUCING the voltage across *R*5 and *R*6. Thus, the *V*7 current reduces the input to the converter stage.

Locate the other *P*3 relay in figure 6–15, which is in the *V*6 grid circuit. When this *P*3 is closed, *R*39 is connected across the *T*3 secondary. Trace out the heavy-lined grid circuit to see that *R*37 SHUNTS THE *T*3 SECONDARY. This means that the bias on the *V*6 grid is only the voltage across the LOWER PART OF *R*37. Result—the bias on *V*6 grid is REDUCED.

With a reduced bias on the grid of *V*6, a MUCH SMALLER RIGHT-TRAIN SIGNAL will fire *V*6 to drive the mount out of the LEFT LIMIT. *R*37 is adjusted so that a SMALL right-train signal is able to drive the mount out of the left limit. As soon as the mount is out of the limit, *P*3 and *P*5 will open and operation is back to normal.

Figure 6–15 explains the limit circuit for left-limit operation. You can figure out what would happen for right-limit operation. *P*2 and *P*5 would close instead of *P*3 and *P*5, and plate 1 of *V*7 would conduct instead of plate 2.

LIMIT CIRCUIT—LOCAL CONTROL

Refer to figure 6–15 and follow the action of the limit-circuit operation for local control.

In local control both the fine and coarse C. T. inputs are cut out. Then, as the mount approaches either limit, the cam-operated switch releases the spring brake and closes either *P*2 or *P*3.

When the mount is in the left limit, *P*3 is closed. This shunts the local tachometer output through *V*7, plate 2, greatly reducing the signal at *R*5 and *R*6.

On the other hand, when the mount is in the right limit, *P*2 is closed, shunting the local tachometer output through *V*7, plate 1, and greatly reducing the signal at *R*5 and *R*6.

Now—all control circuits for the Amplidyne Power Drive, Mk 4, have been completely explained. All amplidyne control circuits work in much the same manner, so understanding the operation of other amplidyne control circuits should be easier.

QUIZ

1. The polarity and strength of the amplidyne output are determined by the input signal to its
   a. power motor
   b. control field
   c. compensating field
   d. quadrature field
2. Into which control circuit are the antihunt signals fed?
   a. Synchronizing
   b. Stabilizing
   c. Converter
   d. Amplifier
3. Into which circuit is the fine-signal fed?
   a. Synchronizing
   b. Stabilizing
   c. Converter
   d. Amplifier
4. The purpose of the Thyrite resistors across the plate loads in the amplifier circuit is to
   a. match the reflected impedance in the plate load
   b. limit the current in the amplidyne control fields
   c. short out the high-frequency signals
   d. balance the plate currents of the tubes under no-signal conditions

5. The purpose of the positive voltage developed across *R*25 and placed on the grids of the tubes in the amplifier circuit is to
   a. bias the tubes at the midpoint of their I_p E_g curves
   b. balance the current in the amplidyne control fields under no-signal conditions
   c. remove distortion from the signal voltages
   d. compensate for tube aging
6. Which plate in the tubes in the converter circuit conducts at the same time that *P*3 conducts?
   a. *P*4
   b. *P*1
   c. *P*2
   d. All of the above
7. Which of the following voltages is applied across the primary of the transformer supplying the grid circuit of the tubes in the converter circuit?
   a. Fine-control signal
   b. Stabilizing voltage
   c. Coarse-control signal
   d. Local-tachometer signal
8. With which of the following signals are the stabilizing voltages combined at the input to the converter stage?
   a. Local-tachometer control
   b. Coarse control
   c. Fine control
   d. All of the above
9. The feedback from the stabilizing generator is effective only when the mount is
   a. traveling at a high speed
   b. reversing
   c. jittering
   d. standing still
10. The purpose of the low-pass filter in the quadrature winding circuit is to
    a. reduce the jitter feedback when the mount is reversing most rapidly
    b. prevent slow movements from becoming stabilizing inputs
    c. prevent high frequencies from feeding back into the amplidyne
    d. reduce the high frequencies due to commutation
11. Which of the following feedback voltages are developed across *R*14 and *R*10 in the stabilizing voltage circuit?
    a. Speed and quadrature
    b. Speed, current, and quadrature
    c. Current and quadrature
    d. Speed and current

12. The purpose of *C*4 and *C*6 in the synchronizing circuit is to
    a. filter harmonics from the grid circuits
    b. prevent signal overload
    c. phase the a-c on the grids exactly 180° out of phase with the a-c on the plate
    d. prevent excessive grid currents

13. If a coarse-signal input of any phase of the synchronizing circuit is strong enough to fire the tubes, the thyratron tubes so operate that
    a. one tube conducts on one alternation of the signal while the other conducts on the other alternation
    b. one tube conducts on one alternation of the signal while the other does not conduct at all
    c. one tube conducts on both alternations of the signal while the other conducts on only one alternation
    d. one tube conducts on both alternations of the signal while the other does not conduct at all

14. What determines the polarity of the output of the local tachometer generator?
    a. Direction in which the generator is turned
    b. Speed with which the generator is turned
    c. Position of the limit switches
    d. Strength of the feedback from the stabilizing tachometer

15. When a mount is about to be driven into its limit, a limit switch tends to stall the drive motor by
    a. shorting out the motor fields
    b. releasing the clutch
    c. releasing the spring brake
    d. engaging the clutch

16. When a mount is about to be driven into its limit, a limit switch cuts out or reduces the signal by
    a. shorting out the signal in the amplifier
    b. shorting out the 115-volt a-c rotor supply
    c. energizing the relay coils
    d. de-energizing the relay coils

17. Closing relays *P*2 or *P*3 in the limit circuits has the effect of
    a. increasing the input to the converter circuit
    b. decreasing the feedback voltages from the stabilizing circuits
    c. shorting out the fine signal in the converter circuit
    d. shorting out the coarse signal or the local tachometer generator signal

18. When the left-limit switch closes the relay in the grid circuit of the thyratron tube in the stabilizing circuit, it has the effect of
    a. decreasing the bias on the left-train tube
    b. decreasing the bias on the right-train tube
    c. increasing the bias on the right-train tube
    d. increasing the bias on the left-train tube
19. Which of the stabilizing voltages is effective when the Mk 4 Amplidyne Power Drive is under coarse control or local control?
    a. Speed only
    b. Jitter only
    c. Current only
    d. All of the above
20. With a d-c signal input the output signal of the converter stage is a
    a. 60-cycle a. c.
    b. 120-cycle a. c.
    c. half-wave rectified d. c.
    d. full-wave rectified d. c.

CHAPTER 7.

AMPLIDYNE CONTROL CIRCUITS, GUN DIRECTOR, MK 37

The Power Drive, Mk 4, is one example of an amplidyne control. There are a number of other amplidyne drives with control circuits of their own, similar in characteristics to the Mk 4, but differing in design. It should be noted, however, that all amplidyne control circuits operate in about the same way.

For example, the Power Drive, Mk 3, is very much like the Mk 4. In fact the two systems are so much alike that if you know the Mk 4, you also know the Mk 3. On the other hand, the control circuits for the amplidyne in the Gun Director, Mk 37, are different. The circuits in the Mk 34 director are much like the Mk 37, so when you know the Mk 37, you also know the Mk 34. By learning certain circuits, therefore, you will be able to follow others. Let us now consider the amplidyne control circuits of the Gun Director, Mk 37.

There are THREE SEPARATE FOLLOW-UP CIRCUITS in the amplidyne control circuits of the Gun Director, Mk 37. First is the circuit in the train receiver-regulator; second, the circuit in the elevation receiver-regulator; and third, the circuit in the cross-level receiver-regulator.

The three converter-amplifier circuits in these three receiver-regulators are exactly alike, so an explanation of one will apply to all three.

The three stabilizing and synchronizing circuits in the receiver-regulators are not alike and will be explained separately.

TRAIN CONVERTER—AMPLIFIER CIRCUIT

The train converter circuit will be used as the example for all converters in the Mk 37 receiver-regulators.

Compare the train converter circuit in figure 7–1 with the converter in the Mk 4, Power Drive, in figure 6–3, paying particular attention to the plate circuits and the balancing adjustments at *R*14.

In the Mk 4 drive one plate from each tube feeds to each side of the output. This system will operate on half-wave if either *V*3 or *V*4 fails. But notice the plate connections in figure 7–1. Both plates of *V*1 feed to *R*3, and both plates of *V*2 feed to *R*4. This means that the output at *R*3 will go dead if *V*1 fails, and the output at *R*4 will go dead if *V*2 fails. The converter output in the Mk 37 is completely unbalanced by a failure of either *V*1 or *V*2. The balancing adjustment at *R*14 adjusts the *V1* and *V*2 biases. It is set so the *R*3 and *R*4 voltages are EQUAL for no-signal.

Trace out the converter circuit in operation. The circuit of figure 7–1 is polarized for an in-phase signal. The solid markings are for alternation *A* and the broken markings are for alternation *B*. You can see that the signal unbalances the *R*3, *R*4 voltages; that is, *R*3 increases for an in-phase signal to train the director right.

The same converter circuit is shown in figure 7–2 for an OUT-OF-PHASE signal. Trace it through. Notice that *V*2 is now passing the large current and *R*4 has the large voltage. The director trains left.

TRAIN STABILIZING CIRCUIT

The stabilizing circuit used in the train amplidyne circuit of the Mk 37 system does exactly the same things as the stabilizing circuit in the Mk 4 power drive.

To refresh your memory—the stabilizing circuit of the Mk 4 COMBINES three stabilizing voltages that OPPOSE the fine signal. Then the combined voltages are fed to the converter grids where they damp the signal to reduce hunting and jitter.

These stabilizing circuits for the Mk 37 are shown in

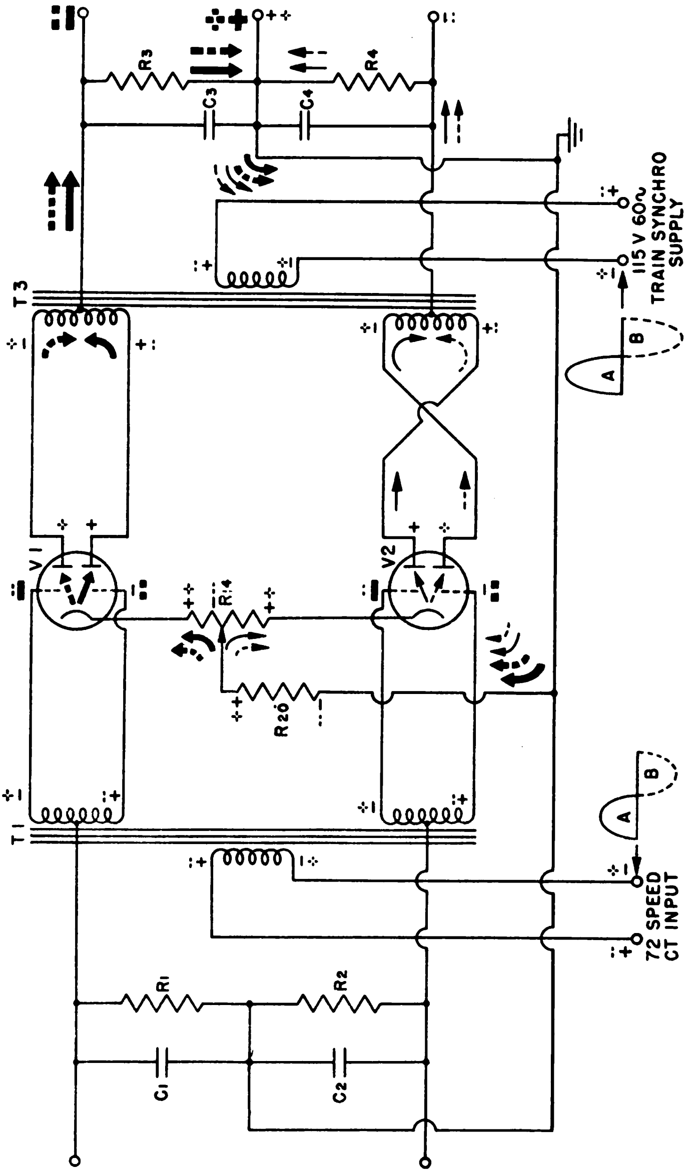


Figure 7-1.—Train converter circuit, right-train.

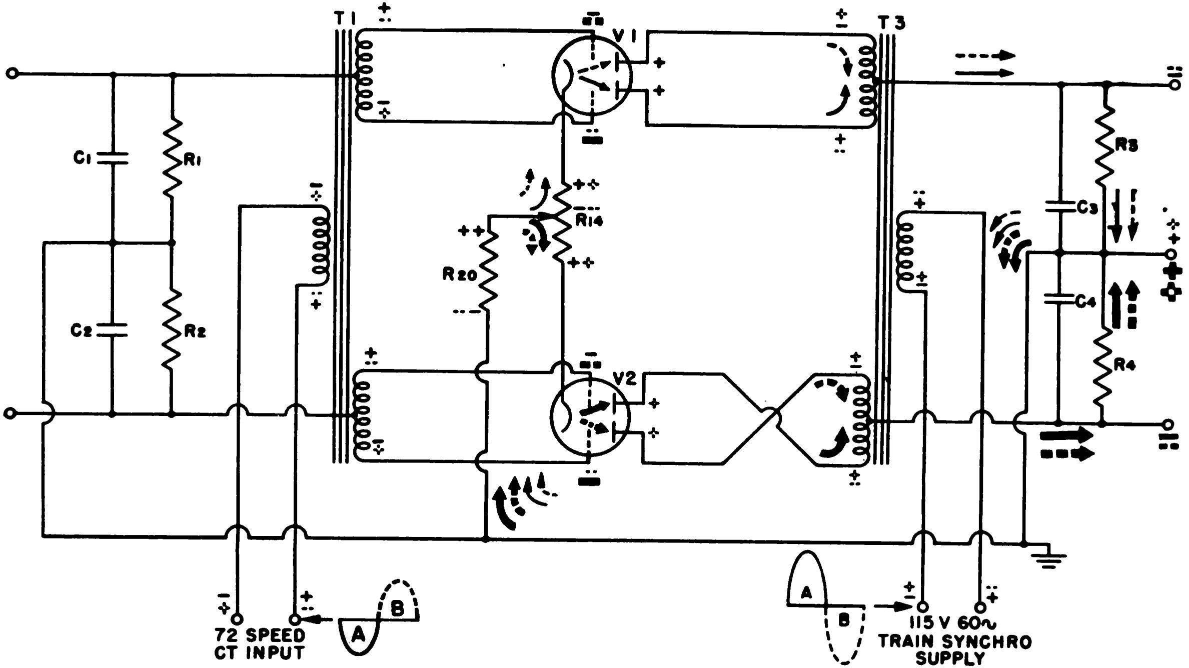


Figure 7-2.—Train converter circuit, left-train.

figure 7–3. Locate the sources of the three stabilizing voltages. You should find the sources of the speed feedback, the current feedback, and the jitter feedback. The speed and jitter feedback sources are the same here as in the Mk 4 Power Drive, while the current feedback source is different. Figure 7–3 shows that the current feedback is taken across the series field of the train drive motor. However, the current feedback is still proportional to the current drawn by the drive motor because the series field of the drive motor and the compensating field of the amplidyne form a series circuit.

Now, trace the stabilizing voltages through their circuits. All three voltages are combined in *R*16, *R*17, and *R*18. This combined voltage is fed to the converter circuit across *R*1 and *R*2. The high-pass filter is made up of *R*15, *C*7, and *C*8 to remove low-frequency voltages.

There is one new circuit in figure 7–3 containing *K*1, *R*21, and *C*9. This circuit is really a part of the synchronizing circuit and works as a stabilizing circuit.

The *K*1 relay in the heavy-lined loop is closed by the synchronizing circuit for large error signals—errors of more than 50 minutes of arc. These same large error signals would tend suddenly to overspeed the mount, but as *K*1 closes, the entire local tachometer voltage from *R*18 is applied across *R*1 and *R*2. This large *R*18 voltage OPPOSES the large error signal. Consequently, the mount gets LESS signal and it does not overspeed.

The action of *K*1 is like a brake as it feeds the large *R*18 damping voltage momentarily because it is applied only while *C*9 is charging through *R*1 and *R*2, but while it is applied, the *R*18 voltage opposes the signal so that the mount cannot suddenly overspeed.

As soon as the error signal is reduced, the mount slows down without the braking action of *K*1. The reduced error signal closes the upper contacts of *K*1, and this shorts out *C*9 through *R*21. After *C*9 has discharged through *R*21, the circuit is again ready to prevent sudden overspeeding.

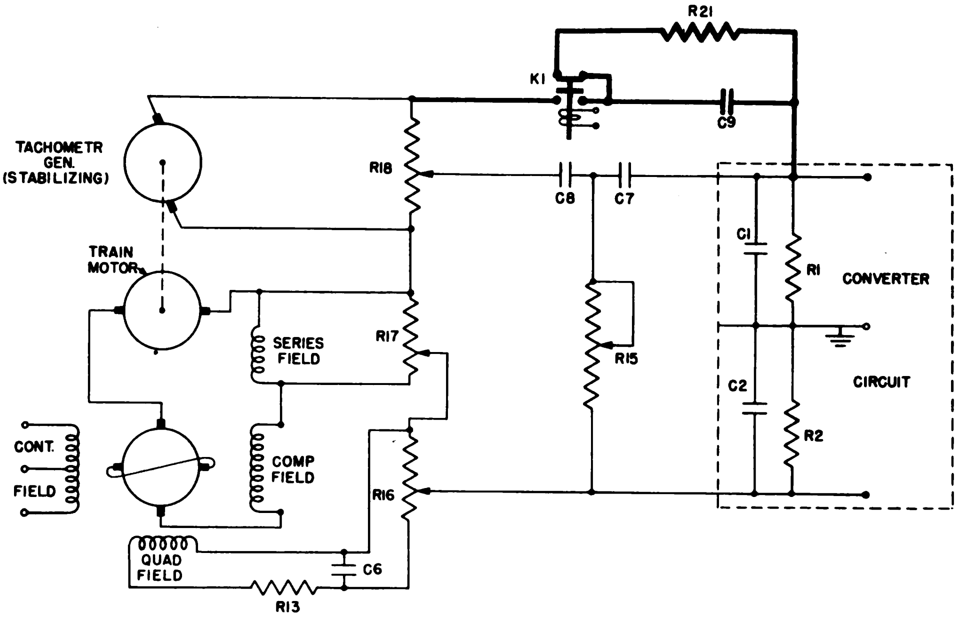


Figure 7-3.—Stabilizing circuit, Mk 37.

TRAIN CIRCUIT

Figure 7–4 shows the complete train circuit for the Mk 37 containing the converter, stabilizing, and amplifier circuits. It can be seen that the amplifier stage, *V*3 and *V*4, is exactly like the amplifier stage in the Mk 4 power drive.

There is one new circuit in figure 7–4, the *V*6 synchronizing circuit, which rectifies and amplifies the fine error signal from the 72-speed C. T.

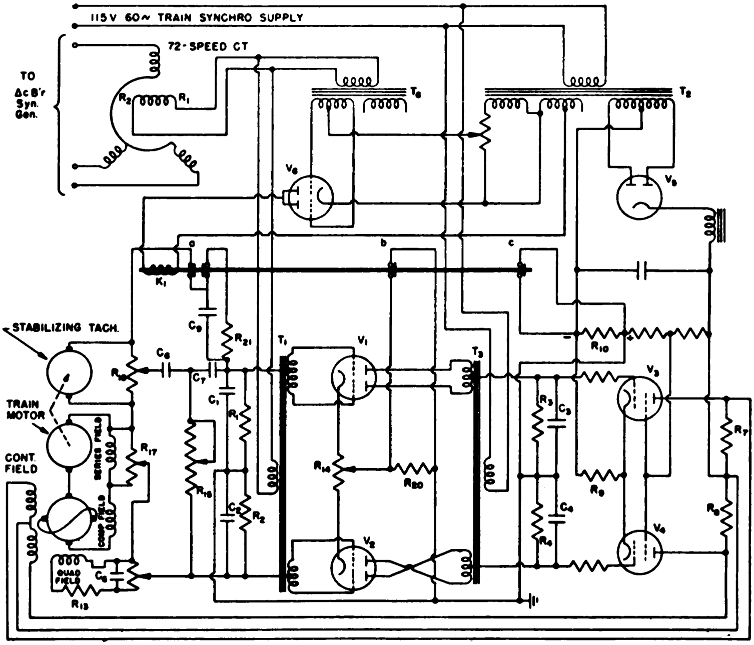


Figure 7–4.—Complete train circuit.

Before you analyze the synchronizing circuit, see how the *K*1 relay system works. *K*1 operates for all error signals over 50 minutes of arc. The relay closes the three sets of contacts at points *a*, *b*, and *c*. The contacts at point *a* connect the *R*18 voltage across *R*1 and *R*2 to dampen any tendency to overspeed suddenly. The contacts at point *c* short out *R*10. This removes the positive *R*10 voltage from the grids of *V*3 and *V*4. Consequently, *V*3 and *V*4 operate with more negative grids, and this reduces the current in the amplidyne control fields. The contacts at point *b* short out the *R*20 voltage. This removes the negative bias from the *V*1 and *V*2 grids. The *V*1 and *V*2 currents increase, and, in turn, increase the *R*3 and *R*4 voltages, which drive the grids of *V*3 and *V*4 more negative. In fact, the increased *R*3 and *R*4 voltages drive the *V*3 and *V*4 grids nearly to cutoff.

Now put the two actions of the contacts at points *b* and *c* together. The contacts at point *c* remove the positive voltage *R*10 from the grids of *V*3 and *V*4, and the contacts at point *b* increase the negative voltages *R*3 and *R*4 on the grids of *V*3 and *V*4, with a result that *V*3 and *V*4 are very near cutoff.

Now, if a large error signal is fed to *V*1 and *V*2, it does not cause a large unbalance in the *V*3 and *V*4 outputs because the plate current of one tube cannot decrease since the tube is already near cutoff. In short, *V*2 and *V*4 are not operating push-pull—the input to the amplidyne control fields is reduced.

The over-all effect of the *K*1 relays is to reduce the sensitivity. The sensitivity is reduced only for large error signals, to prevent overspeeding.

TRAIN SYNCHRONIZING CIRCUIT

Analyze the details of the train synchronizing circuit in figure 7–4. This is the circuit that controls the *K*1 relay for large error signals. In other words, this is the circuit that applies the brake when the mount attempts to overspeed.

The braking action is necessary because the train circuit receives its signal from a single 72-speed synchro system. The synchro system means that it is possible for the train receiver-regulator to synchronize at 72 different points. However, the trainer at the director sets the initial train setting and, from then on, the director is trained at the rate transmitted from the computer. So, practically, the receiver-regulator will synchronize at the correct point unless overspeed accelerates the director to the next point of synchronism.

This means that the single 72-speed system will produce correct synchronism if overspeed is prevented. That's why the synchronizing circuit is designed to apply the *K*1 brake.

There is no need for a brake when the error signal is less than 50 minutes. Therefore, the *K*1 relay does not operate below this amount of error. Also, eliminating the braking action during small errors will increase sensitivity. This increases the accuracy for small errors.

The complete synchronizing circuit is shown in figure 7–5. The figure is polarized for a zero error, or for a small error signal—less than 50 minutes. Let us trace out the plate and grid circuits for alternation *B* of the supply by following the broken arrows.

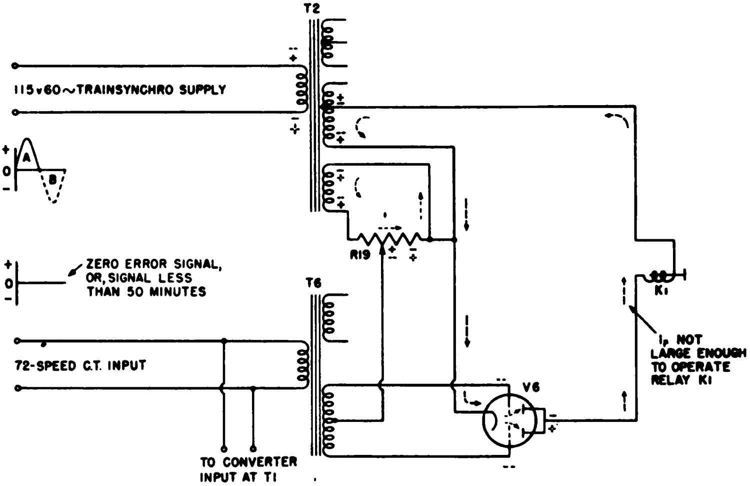

T2
115v60~TRAINSYNCHRO SUPPLY
A
B
R19
ZERO ERROR SIGNAL, OR, SIGNAL LESS THAN 50 MINUTES
T6
K1
72-SPEED C.T. INPUT
V6
I_P NOT LARGE ENOUGH TO OPERATE RELAY K1
TO CONVERTER INPUT AT T1

Figure 7–5.—Synchronizing circuit, no signal.

*K*1 is connected in series with the plate of *V*6 and whatever current flows through *V*6 also flows through *K*1. The grids of *V*6 are biased by the large voltage across the secondary of *T*2 which nearly blocks *V*6. *V*6 passes only a small current through *K*1 which is not enough to operate the *K*1 brake. When the plates of *V*6 are positive, the bias on both grids is negative.

The circuit in figure 7–6 shows what happens for a large left-train error signal. The error signal is added to the grids at *T*6 and this large error signal drives the bottom grid less negative. This action may be seen by checking the polarities in figure 7–6.

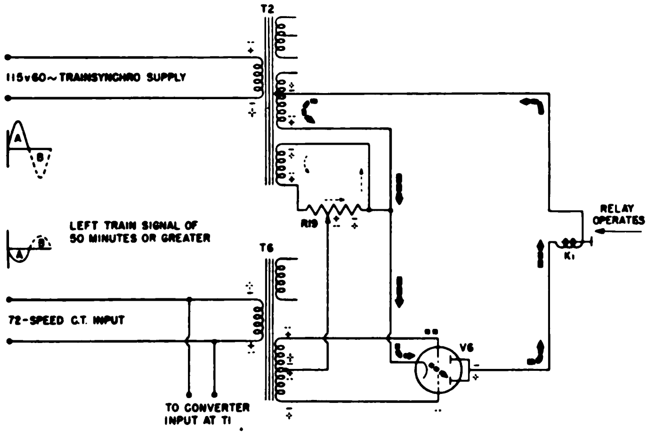


Figure 7–6.—Synchronizing circuit, left-train.

The less negative grid increases the I_p of the bottom plate which makes the *V*6 current large enough to operate *K*1. When the contacts of *K*1 close, the signal is reduced and the mount is braked.

Figure 7–7 shows a large right-train error signal. Trace out the circuit by following the broken arrows for alternation *B*. The top plate of *V*6 now has the large I_p which closes the contacts of *K*1 and the mount is braked. *R*19 adjusts the *V*6 bias so that *K*1 operates at 50 minutes of error.

You're probably wondering what happens during alternation *A*. During alternation *A* the plates of *V*6 are negative. Since the plates are negative, no current will flow, hence, no current through *K*1. *K*1 relay is designed to operate on half-wave pulses which means that 60 pulses a second will hold *K*1 closed. Therefore, it does not fall out between the *B* alternation pulses even though no current flows through *K*1 during the *A* alternation.

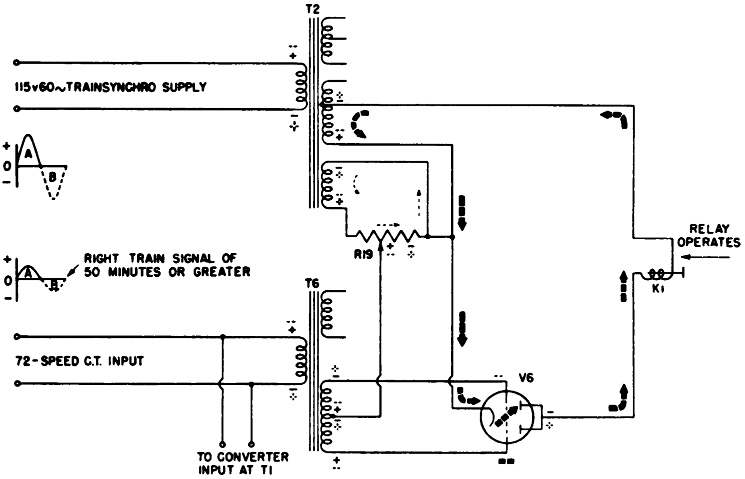


Figure 7–7.—Synchronizing circuit, right-train.

CROSS-LEVEL CONTROL CIRCUIT

The converter and the amplifier circuits in the cross-level control are just like the converter and amplifier circuits in the train control. The stabilizing and synchronizing circuits are different, however, and will be explained.

CROSS-LEVEL STABILIZING CIRCUIT

The cross-level stabilizing circuit does the same job as any other stabilizing circuit—it removes hunt and jitter. It does its job in about the same way as the Mk 4 circuit by feeding voltages into the converter circuit to oppose the signal.

The new and different parts of the cross-level stabilizer are the sources of the stabilizing voltages, as shown in figure 7–8.

The current feedback voltage in figure 7–8 is tapped across the series field of the drive motor. This voltage goes into the stabilizing circuit at *R*17.

The speed feedback voltage is tapped across the amplidyne output terminals. The voltage across the amplidyne output terminals is proportional to the speed of the drive motor, because the amplidyne output voltage depends on the amplidyne load. The amplidyne load is the drive motor. As the motor speeds up, counter emf reduces the load so the amplidyne terminal voltage increases. This speed feedback voltage goes into the stabilizing circuit at *R*18.

The jitter feedback voltage comes from the quadrature winding and this voltage goes into the stabilizing circuit at *R*16.

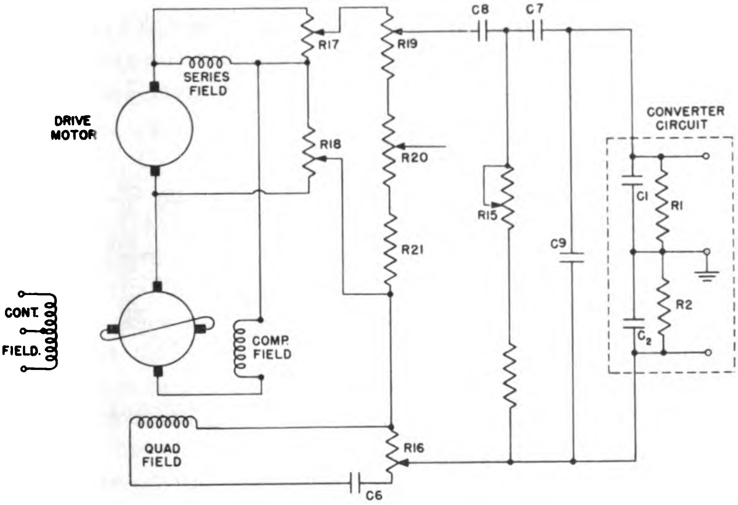


Figure 7–8.—Stabilizing circuit.

The current and speed feedbacks are combined across *R*19, *R*20, and *R*21. *R*19 adjusts the amount of this combined feedback and then the combined current and speed feedback is added to the jitter feedback at *R*16.

A high-pass filter *C*7, *C*8, *R*15 removes low-frequency feedback. Thus, only the hunt and jitter feedbacks get into the converter circuit.

Finally, the total stabilizing feedback is fed to the converter circuit across *R*1 and *R*2.

SYNCHRONIZING CIRCUIT

The cross-level synchronizing and stabilizing circuits are shown in figure 7–9.

For errors of 80 minutes or more, the synchronizing circuit feeds the 2-speed C. T. signal to the converter. For errors of less than 50 minutes, it cuts out the 2-speed C. T. signal and feeds in the 72-speed C. T. signal.

Here's what the synchronizing circuit does. *V*6 is biased near cutoff, but when the error exceeds 80 minutes, one of *V*6 grids allows enough current to pass through *V*6 to operate *K*3, which opens the contacts at point *a*. This interrupts the 72-speed C. T. signal at *T*1. At the same time, *K*3 closes the contacts at points *b* and *c*. This completes the synchronizing circuit as shown by the heavy lines in figure 7–9.

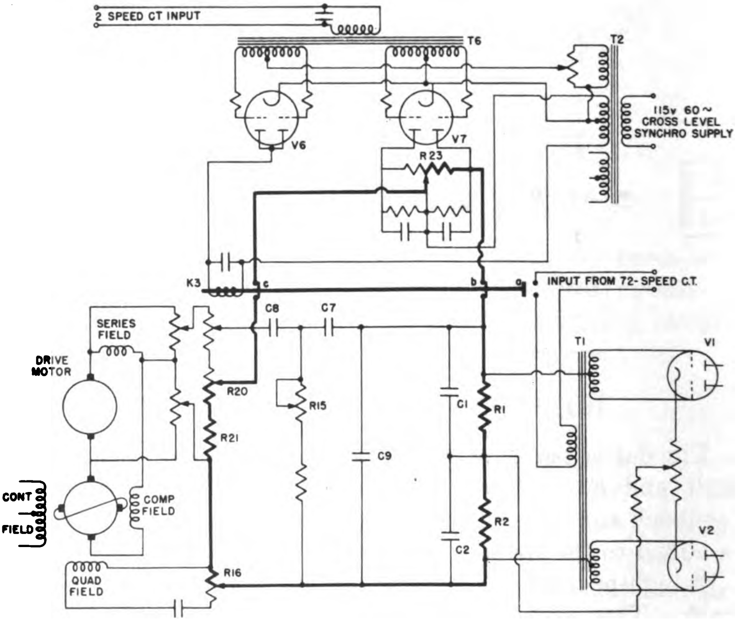


Figure 7–9.—Synchronizing circuit.

The synchronizing voltage is the amplified and rectified 2-speed C. T. signal. It comes from *V*7 and is fed into the synchronizing circuit across *R*23. This *R*23 voltage is ADDED to the stabilizing feedbacks at *R*20, *R*21, and *R*16. Finally, the combined synchronizing and stabilizing voltages are fed to the converter at *R*1 and *R*2.

Notice that *K*3 also bypasses *C*7 and *C*8. Thus, during coarse control, the d-c current and speed feedbacks are added directly to *R*1 and *R*2. These d-c feedbacks brake the mount to prevent any overspeeding that might result from over-large error signals.

SYNCHRONIZING CIRCUIT DETAILS

You know what the synchronizing circuit does. Now find out how it works. Look at figure 7–10.

The PHASE of the error signal from the 2-speed C. T. depends on whether the cross-level angle is increasing or decreasing. In this case the error signal is out-of-phase for an increasing angle.

Figure 7–10 shows the synchronizing circuit in detail. The diagram is polarized for an OUT-OF-PHASE error signal of more than 80 minutes.

First, trace out the plate supply for *V*6 and *V*7. Both tubes get their plate supply from the middle secondary of *T*2. *T*2 is energized by the cross-level synchro supply. The error signal is out-of-phase with this supply voltage.

Now check the plate polarities in figure 7–10. Both *V*6 plates are positive for alternation *B*, and both *V*7 plates are positive for alternation *A*. This means that *V*6 can pass current only during alternation *B*, and *V*7 can pass current only during alternation *A*.

Follow the operation of *V*6 which is biased nearly at cutoff by the top secondary of *T*2. But the error signal at *T*6 REDUCES this bias. When the error signal exceeds 80 minutes, the bias is reduced enough so that the *V*6 current operates *K*3. Although *V*6 passes current only on alternation *B*, this pulsating current holds the *K*3 contacts closed. By following the broken arrows in figure 7–10, you can trace out the operation of *V*6.

Now use figure 7–10 to trace out the operation of *V*7 for NO-SIGNAL at *T*6. The two plate currents of *V*7 are equal. This balances the voltages across *R*28 and *R*29—there is no current through *R*23 and no output to the converter.

Now trace out the *V*7 operation for an OUT-OF-PHASE

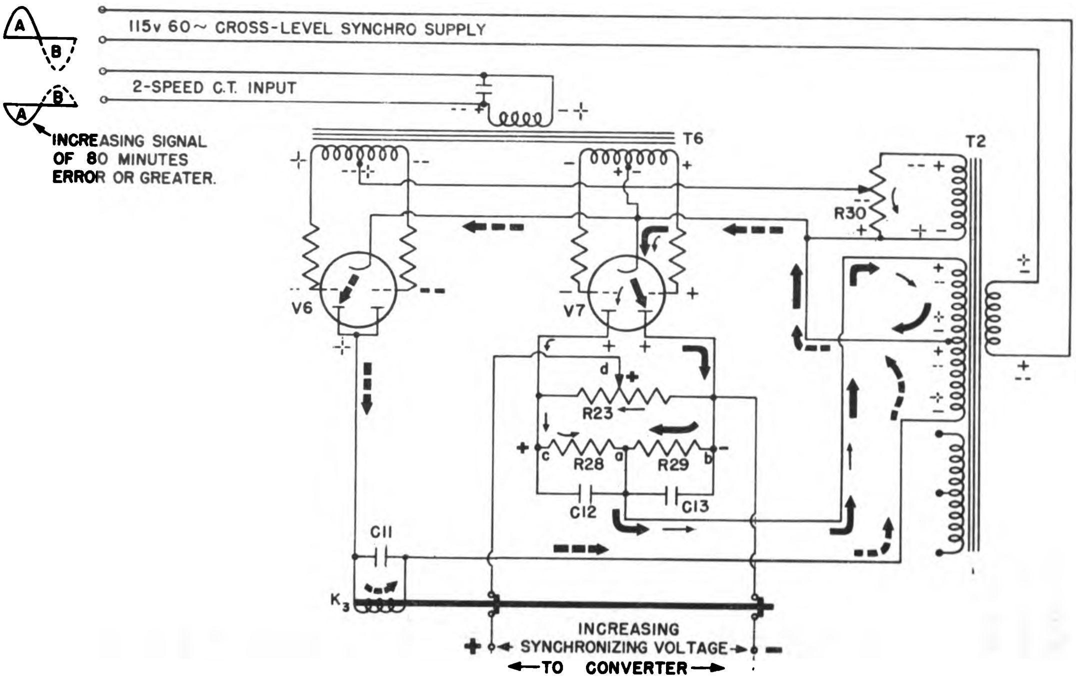


Figure 7–10.—Synchronizing circuit, out-of-phase signal.

signal at *T*6. The signal drives the left-hand grid more negative, and the right-hand grid less negative. The *R*29 current increases and the *R*28 current decreases. This makes point *b* negative with respect to point *c*.

The *b*-to-*c* voltage is across *R*23, and it forces a current through *R*23. Point *d* in *R*23 becomes positive with respect to point *b*. Finally, this *b*-to-*d* potential becomes the converter input. *C*12 and *C*13 filter the pulses from *V*7. Thus, the *R*23 voltage to the converter is fairly steady.

You'll understand the operation of *V*7 by following the solid arrows in figure 7–10.

Figure 7–11 shows the synchronizing circuit operating with an IN-PHASE signal of 80 or more minutes of error. For the in-phase signal, the opposite plate of *V*6 conducts. The result is the same—*K*3 operates to close its contacts.

Trace out the *V*7 plate and grid circuits in figure 7–11. Notice the *V*7 grid polarities; they are opposite to the polarities for an out-of-phase signal. Result—the *R*23 current is reversed. Now point *d* is negative with respect to point *b*, and this *d*-to-*b* potential becomes the input to the converter circuit.

You can trace out the *V*7 operation by following the solid arrows in figure 7–11.

Before you leave the synchronizing circuit for the cross-level amplidyne control, go back to figure 7–9 and trace both in-phase and out-of-phase signals through this complete circuit. Be sure to see how signals of more than 80 minutes of error operate the synchronizing circuit. *V*6 controls *K*3 to open the fine C. T. circuit and close the coarse C. T. circuit. *V*7 rectifies and amplifies the coarse C. T. signal. Finally, the coarse C. T. signal is combined with the stabilizing voltages and fed to the converter circuit.

ELEVATION CONTROL CIRCUITS

The elevation stabilizing circuit is just like the cross-level stabilizing circuit, and the elevation converter-amplifier circuit is just like the train and cross-level converter amplifiers.

The elevation circuit has NO SYNCHRONIZING circuit. It does not need a synchronizing circuit because the elevation

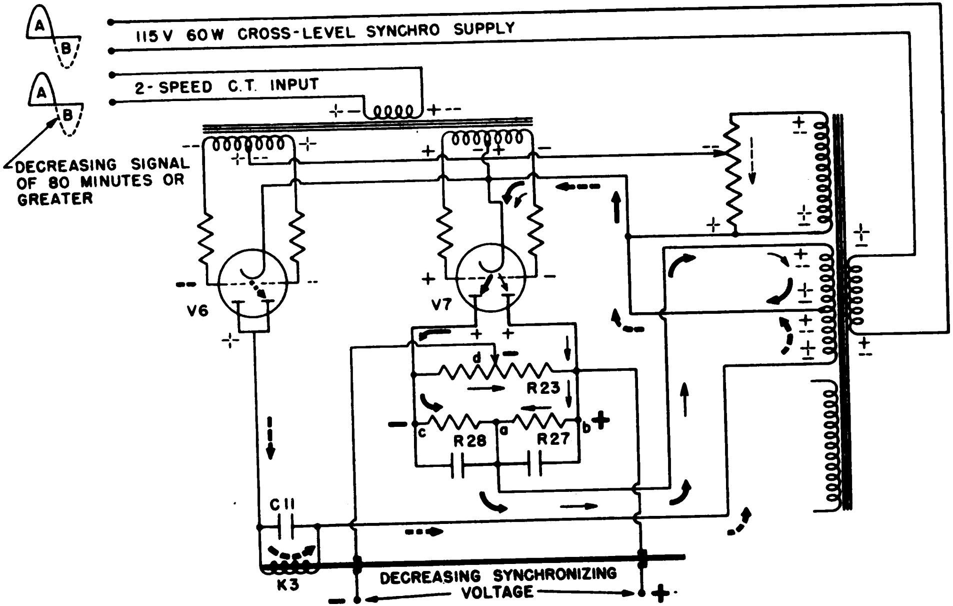

115 V 60 W CROSS-LEVEL SYNCHRO SUPPLY
2-SPEED C.T. INPUT
A
B
DECREASING SIGNAL OF 80 MINUTES OR GREATER
V6
V7
R23
R27
R28
a
b
c
d
C11
K3
DECREASING SYNCHRONIZING VOLTAGE

Figure 7–11.—Synchronizing circuit, in-phase signal.

gear is LIGHT. There is no danger of the elevation gear overspeeding and overdriving into the next point of synchronism.

QUIZ

1. How many separate follow-up circuits are there in the amplidyne control circuits of the Mk 37 Gun Director?
    a. 2
    b. 3
    c. 5
    d. 6
2. Which circuits in the receiver-regulator are exactly alike?
    a. Synchronizing
    b. Stabilizing
    c. Limiting
    d. Converter-amplifier
3. Which pair of plates in the train converter circuit conducts the greater currents when an out-of-phase signal is applied?
    a. Both plates in *V*2
    b. Both plates in *V*1
    c. Left-hand plates in the tubes
    d. Right-hand plates in the tubes
4. The circuit containing *K*1, *R*21, and *C*9 in the train synchronizing circuit prevent overspeeding by opposing the action of a
    a. large jitter feedback signal
    b. large speed feedback signal
    c. large error signal
    d. high-pass filter
5. The purpose of *V*5 in the train circuit is to
    a. provide the plate voltage for the amplifiers
    b. rectify the fine-error signal
    c. bias the amplifiers near cutoff on large error signals
    d. short out the amplifier output when the mount approaches a limit
6. Which train circuit controls relay *K*1?
    a. Amplifier
    b. Converter
    c. Synchronizing
    d. Stabilizing

7. The braking action of relay *K*1 on large error signals is necessary in order to prevent the director from
   a. overloading the drive motor
   b. overloading the amplifier tubes
   c. overspeeding into the next point of synchronism
   d. developing excessive stabilizing voltage

8. A large error signal causes relay *K*1 to close by
   a. increasing the bias on *V*6
   b. increasing the plate voltage on *V*6
   c. opposing the bias on *V*6
   d. completing the cathode circuit on *V*6

9. In what way does the cross-level stabilizing circuit differ from the train stabilizing circuit?
   a. In the point at which the stabilizing voltages are fed back into the system
   b. In the sources of the stabilizing voltages
   c. In that it removes hunt and jitter
   d. In the manner in which the stabilizing voltages are combined

10. The purpose of *V*7 in the cross-level synchronizing circuits is to
    a. operate relay *K*3
    b. provide plate voltage for *V*6
    c. amplify the input from the 72-speed C. T.
    d. rectify and amplify the input from the 2-speed C. T.

11. The phase of the error signal input to the cross-level synchronizing circuit from the 2-speed C. T. is determined by the
    a. rate of change of the cross-level angle
    b. size of the cross-level angle
    c. direction in which the director is training
    d. direction in which the cross-level angle is changing

12. Because there is no danger of the elevation gear overspeeding and overdriving into the next point of synchronism, the elevation circuit has no
    a. stabilizing circuit
    b. amplifier circuit
    c. converter circuit
    d. synchronizing circuit

CHAPTER 8

GUN DIRECTOR, MK 38

The TRAIN DRIVE is the only AMPLIDYNE drive in the Gun Director, Mk 38. The control circuits for this one amplidyne are easy. They do the same job as the control circuits in the Mk 37, but they do the job in a little different way.

CONVERTER-AMPLIFIER

Figure 8–1 shows the converter-amplifier in the Gun Director, Mk 38 train amplidyne control circuit.

The amplifier shown in figure 8–1 is made up of *V*2, *V*3 and their circuits. *V*2 and *V*3 have directly-heated cathodes (the filaments act as the cathodes of these tubes).

Here's the grid circuit of *V*2—grid, *R*6, *R*9, filament transformer at *T*2, filament. Now trace out the *V*3 circuit.

Notice the bias voltage on the grids of *V*2 and *V*3. The *V*2 grid is biased by the voltage across *R*6 and *R*9, and the *V*3 grid is biased by the voltage across *R*7 and *R*9.

Now check the polarities of the *R*6, *R*7, and *R*9 voltages. The *R*6 and *R*7 voltages to the grids are NEGATIVE, but the *R*9 voltage to the grids is POSITIVE. Thus, the bias on either the *V*2 or *V*3 grid is the DIFFERENCE between the *R*6 or *R*7 voltage and the *R*9 voltage.

For NO-SIGNAL the *R*6 and *R*7 voltages are larger than the *R*9 voltage. In fact, the *R*6 and *R*7 voltages are just large enough to bias *V*2 and *V*3 for class A push-pull operation. Also, for no-signal the *R*6 and *R*7 voltages are EQUAL. This produces a balanced *V*2, *V*3 output and a balanced input to the amplidyne control fields.

The CONVERTER circuit of figure 8–1 is composed of *V*1 and its circuit. *V*1 is a half-wave rectifier because both

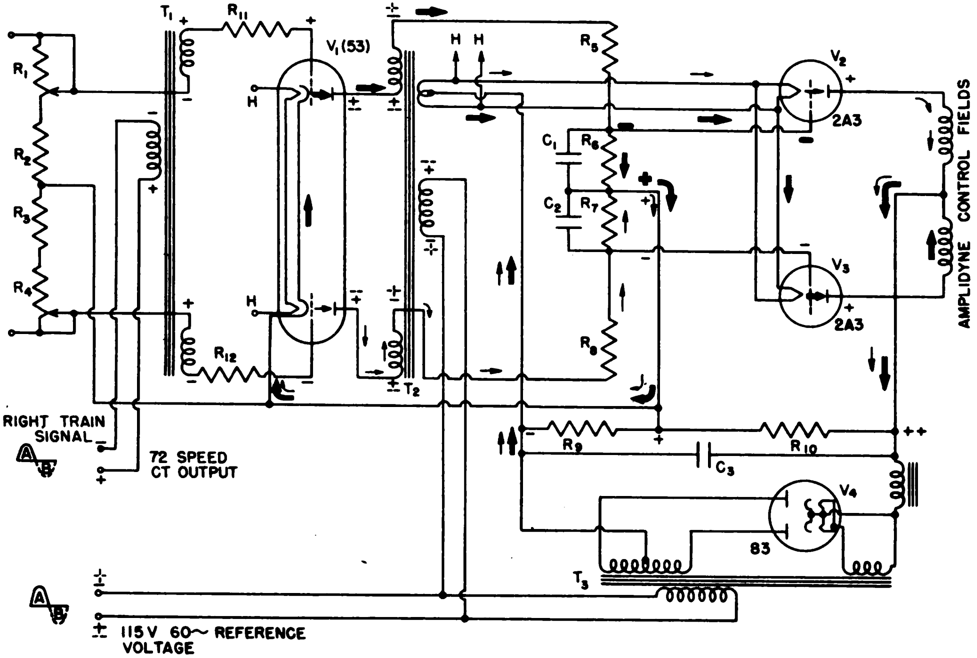


Figure 8-1.—Converter-amplifier circuit, right-train.

plates go positive at the same time. You can see this by checking the plate connections at the *T*2 secondaries.

The top plate of *V*1 is coupled to the grid of *V*2, via the voltage divider, *R*5, *R*6. The bottom plate of *V*1 is coupled to the grid of *V*3, via the voltage divider, *R*7, *R*8.

With no-signal at *T*1, the two plates of *V*1 carry equal currents. This makes the *R*6 and *R*9 voltages equal and the outputs of *V*2 and *V*3 are BALANCED.

Notice that *V*1 has no biasing resistor in the cathode circuit. This means that a positive signal at *T*1 drives the *V*1 grids positive, and positive grids draw current. *R*11 and *R*12 are there to minimize this grid current.

Right-Train Signal

Figure 8–1 is polarized for an IN-PHASE signal. In the Mk 38 director, an in-phase signal produces RIGHT TRAIN.

Notice that *V*1 operates ONLY on alternation *A*—its plates are NEGATIVE on alternation *B*.

During alternation *A* the 72-speed C. T. signal makes the top *V*1 grid positive and the bottom *V*1 grid negative. This increases the I_p of the top plate and decreases the I_p of the bottom plate. The result is that the *R*6 voltage increases and the *R*7 voltage decreases.

The increased *R*6 voltage makes the *V*2 grid MORE negative, hence, the *V*2 current decreases. At the same time the decreased *R*7 voltage makes the *V*3 grid LESS negative, hence, the *V*3 current increases. The final result is that the amplidyne control fields are UNBALANCED to produce RIGHT TRAIN.

Left-Train Signal

Figure 8–2 shows how the converter amplifier works for an out-of-phase or left-train signal.

The *V*1 plates operate only on alternation *A*. With the out-of-phase signal the bottom *V*1 grid is driven POSITIVE and the top *V*1 grid is driven MORE NEGATIVE during alternation *A*. This increases the *R*7 voltage and decreases the *R*6 voltage. The result is that the *V*2 current increases and the *V*3 current decreases. This unbalances the amplidyne control fields to produce LEFT TRAIN.

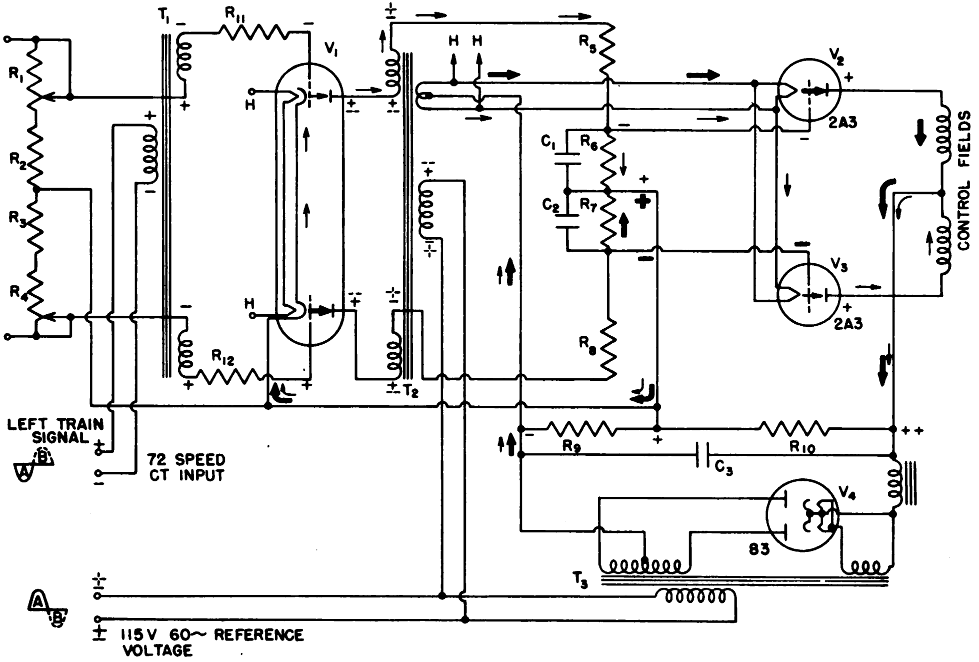


Figure 8-2.—Converter-amplifier circuit, left-train.

Before you leave the converter-amplifier circuit, compare the polarities in figures 8–1 and 8–2. Be sure to see that the PHASE of the signal at *T*1 controls the *V*2 and *V*3 outputs, and these outputs unbalance the amplidyne control fields for either right or left train.

STABILIZING CIRCUIT

The stabilizing circuit in the Gun Director, Mk 38, is called the antihunt circuit. The antihunt circuit is simpler than the stabilizing circuits you've studied, but it does the same job—it combines three feedbacks with the signal at the converter.

Figure 8–3 shows the feedback sources of the antihunt circuit. The CURRENT FEEDBACK is across *R*13. This feedback comes from the series field of the drive motor and from one of the compensating fields of the amplidyne.

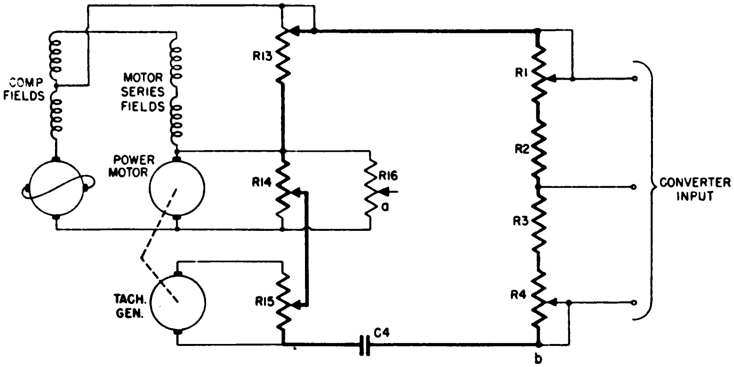


Figure 8–3.—Antihunt circuit.

The VELOCITY FEEDBACK (speed feedback) is across *R*15. This feedback comes from the tachometer generator.

An additional speed feedback is across *R*14. This is called the voltage feedback and it comes from the armature of the drive motor and is proportional to the speed of the drive motor.

Notice that there is no jitter feedback from the quadrature winding. The Mk 38 is one of the earlier directors—it has no jitter feedback. However, the speed feedback from the tachometer helps to prevent jittering and hunting.

The three feedbacks are combined across *R*13, *R*14, and *R*15, and are then fed to the converter across *R*1, *R*2, *R*3, and *R*4.

*C*4 is the high-pass filter; it attenuates all feedback frequencies that are lower than the hunt frequency.

The adjustments at *R*13, *R*14, and *R*15 are set to combine the correct percentage of each feedback, and then the adjustments at *R*1 and *R*4 are set to feed the correct amount of combined feedback to the converter grids. *R*1 and *R*4, also, balance the inputs to the converter grids.

SYNCHRONIZING CIRCUIT

The train circuit in the Mk 38 gets its signal from a single 72-speed C. T., just as the train circuit in the Mk 37 does. Whenever a system is controlled by a SINGLE SIGNAL, there is danger of overspeeding on a large-error signal. As has been pointed out, the result of overspeeding is that the mount overdrives into the next point of synchronism.

The Mk 38 synchronizing circuit prevents overspeeding. When an overlarge signal tends to overspeed the mount, the synchronizing circuit acts as a brake by reducing the overlarge signal in the following manner. The synchronizing circuit INCREASES the amount of stabilizing voltage fed to the converter grids. This increased stabilizing voltage opposes the overlarge signal. As a result the net signal input is reduced and the mount does not overspeed.

The synchronizing circuit applies the brake by shorting out *C*4 in the stabilizing circuit. Shorting out *C*4 puts the *R*13, *R*16 d-c voltages directly across *R*1, *R*2, *R*3, and *R*4, where they OPPOSE the signal and REDUCE the input to the converter grids.

Refer to figure 8–3 and find points *a* and *b*. The synchronizing circuit is connected across these two points, which shorts out *C*4 and connects the *R*13, *R*16 voltage directly across the converter input.

SYNCHRONIZING-STABILIZING CIRCUIT

The complete synchronizing-stabilizing circuit is shown in figure 8–4. The two gas-filled triodes *V*5 and *V*6 in the synchronizing circuit are controlled by the error signal. When the error signal becomes 150 percent larger than normal, the tubes conduct. The conducting tubes bypass *C*4, to put the *R*13, *R*16 d-c voltages directly on the *R*1, *R*4 converter input.

*V*5 and *V*6 each contain a small electrode called the STARTER ANODE connected to the *T*4 secondaries. The *T*4 secondaries put the error signal on the starter anodes and when this error signal is large enough, the starter anodes conduct current from the cathode. This is called the STARTER CURRENT. The starter current fires the tube so that the main plate conducts. This main plate current is through *R*1, *R*4, *R*13 and *R*16 for either the *V*5 or the *V*6 plate current. This is necessary because only one of the tubes, *V*5 or *V*6, is firing at any one time.

*V*5 fires when its starter anode is made POSITIVE by the error signal at *T*4 and when its main plate is made POSITIVE by the stabilizing voltage at *R*16. The phase of the error signal at *T*4 determines which tube fires.

Synchronizing Circuit, Right-Train

Refer to figure 8–4 and trace out the synchronizing circuit for an overlarge right-train error signal. The circuit diagram is polarized for alternation *A* of this error signal. *V*5 fires for alternation *A* because the error signal at *T*4 makes the *V*5 starter anode positive, and the stabilizing voltage at *R*16 makes the *V*5 main plate positive.

Now follow the *V*5 current arrows—*V*5 plate, *R*16, *R*13, *R*1, *R*2, *R*3, *R*4, *V*5 cathode. Result—the *R*16, *R*13 stabilizing voltage acts across *R*1, *R*4 to REDUCE the error signal.

Trace out the *V*1 grid circuit to see how the stabilizing voltage opposes the signal at *T*1.

The action of the starter anode of *V*5 is important in that *V*5 conducts only because the starter anode is made positive enough by the large error signal at *T*4. When the error sig-

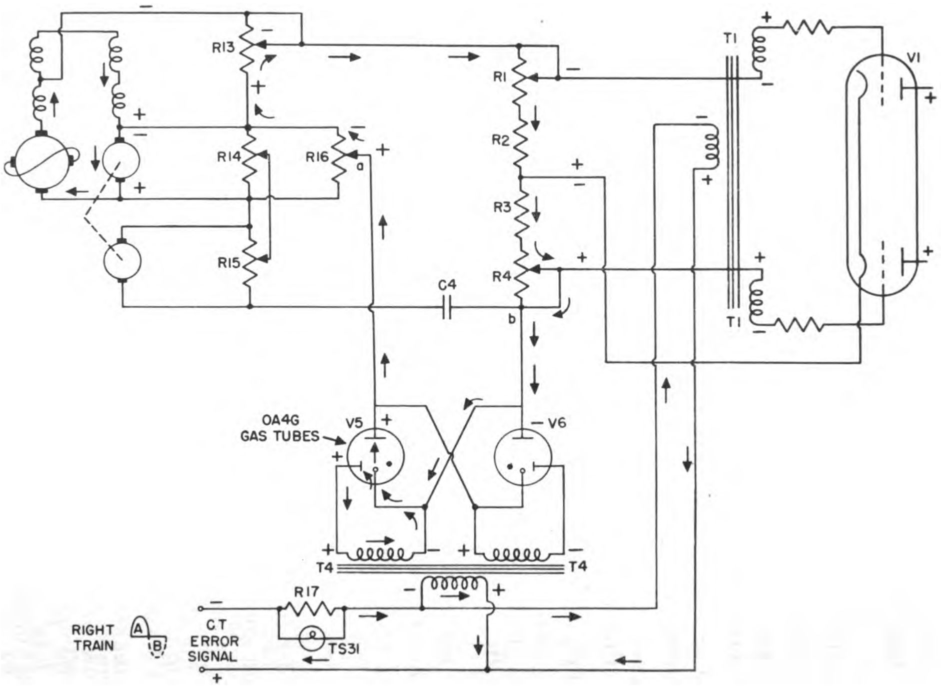


Figure 8-4.—Synchronizing-stabilizing circuits.

nal at *T*4 becomes normal, *V*5 stops conducting because the anode to cathode is less than the extinction voltage. This takes the synchronizing circuit out of the stabilizing circuit. The normal stabilizing voltages are across *R*1, *R*4.

The plate voltage on *V*5 and *V*6 is controlled by *R*16, which is adjusted so that *V*5 and *V*6 fires when the error signal is about 150 percent of normal.

You don't have to worry about alternation *B* of the error signal, because the *V*1 plates are NEGATIVE for alternation B, and the converter circuit does not operate on alternation *B*.

There is another braking circuit in the synchronizing circuit—the *R*17, *TS*31 combination. For a normal error signal, *TS*31 has negligible resistance—it does not reduce the error signal. A large error signal drives enough current through *TS*31 to heat up the filament and INCREASE its resistance. Result—the *R*17, *TS*31 combined resistance increases, and this increased resistance further reduces the error signal to both *T*4 and *T*1.

Synchronizing Circuit, Left-Train

The synchronizing circuit for overlarge left-train error signal is shown in figure 8–5. Notice that the left-train stabilizing voltage is opposite to that of the right train. This makes the *V*6 plate positive. Also, alternation *A* of the left-train error signal at *T*4 makes the *V*6 starter anode positive. Thus, for left train, *V*6 will do the conducting to bypass *C*4.

Follow the *V*6 plate current arrows in figure 8–5. Notice the current in *R*1, *R*4. It's OPPOSITE to the right-train current from *V*5, but the *V*6 current sets up a voltage which OPPOSES the *T*1 error signal because the left-train error signal is OPPOSITE in phase to the right-train signal.

The *R*17, *TS*31 combination acts just the same for either a left-train or right-train error signal. If the signal is overlarge, *TS*31 increases the resistance of the *R*17, *TS*31 combination. This reduces the error signal to both *T*4 and *T*1.

Compare the current flow in figures 8–4 and 8–5. You will see that *V*5 conducts for a large right-train error signal, and *V*6 conducts for a large left-train error signal—and regardless

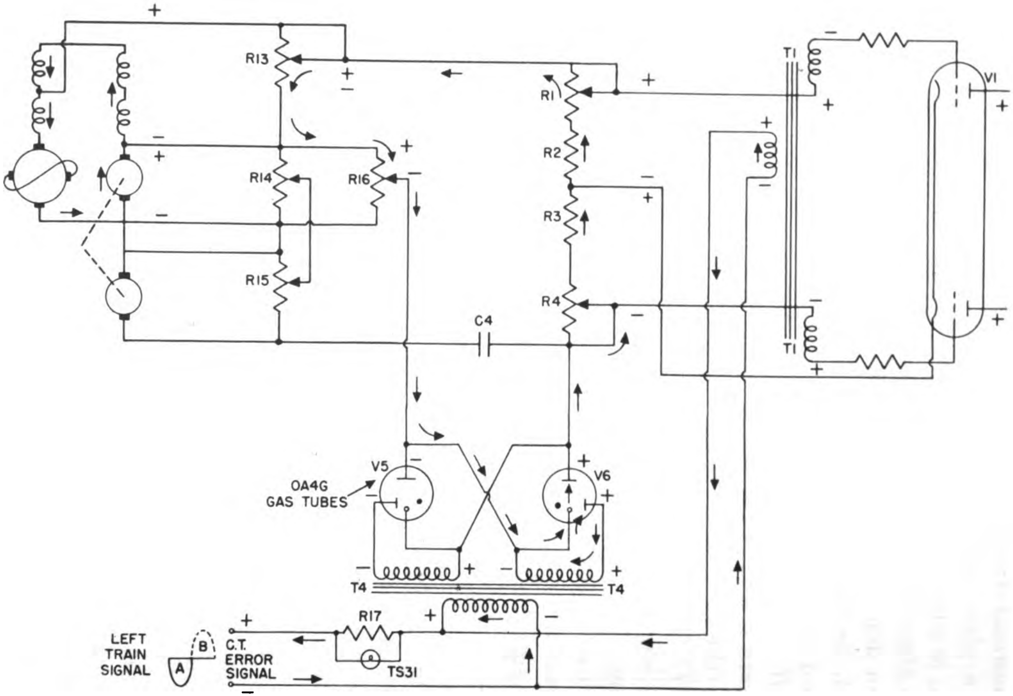


Figure 8-5.—Synchronizing circuit, left-train.

of which tube conducts, *C*4 is bypassed by the synchronizing circuit. Bypassing *C*4 puts the *R*13, *R*16, d-c voltages directly on the converter input to reduce the error signal and prevent overspeeding.

POWER DRIVE, MK 9

The Amplidyne Power Drive, Mk 9, is used on the 40-mm quad mount. This mount is heavy, and if it overspeeds on a large-error signal, the weight of the mount carries it through correspondence. In short, this mount tends to overdrive when it overspeeds.

The problem, then, is to prevent overspeeding for large-error signals and, at the same time, to keep the amplidyne sensitive for small-error signals. This problem is solved by three circuits included in the amplidyne control circuits. The Mk 9 is shown in figure 8–6. The converter-amplifier, stabilizing, and synchronizing blocks are identical to those in the Mk 37. This leaves the three blocks that are new—the synchronizing-aid circuit, the acceleration-limiting circuit, and the limit circuit. These three circuits prevent overspeeding and overdriving.

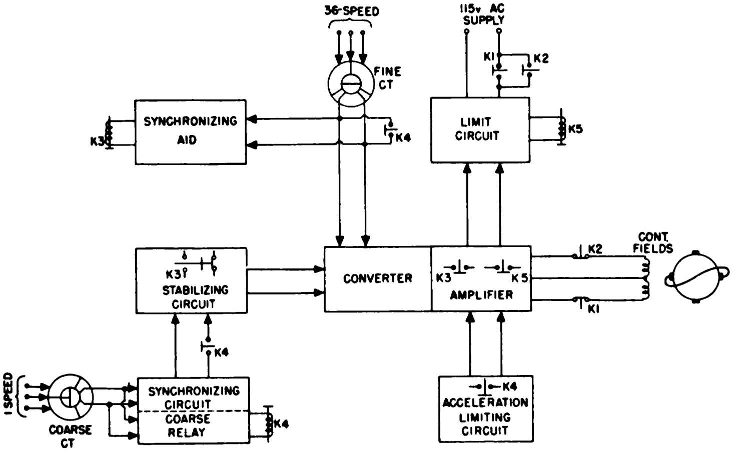


Figure 8–6.—Power Drive, Mk 9—automatic control.

Before getting into the details of the new circuits, get an over-all picture of the circuits operating in automatic control. This will show you what each block does.

When the fine-error signal becomes larger than one degree, the synchronizing aid becomes active and energizes the *K*3 relay. The *K*3 relay does two things. First, it rearranges the stabilizing circuit so that the stabilizing circuit furnishes a large voltage to OPPOSE the signal. Second, *K*3 rearranges the amplifier circuit so that the amplifier loses its sensitivity for a large-error signal. Net result of the *K*3 action—the signal is decreased to prevent overspeeding.

When the error is larger than 4°, the coarse C.T. has control. The coarse relay circuit closes *K*4 and *K*4 does three things. First, it completes the synchronizing circuit; second, it shorts-out the fine C.T.; and third, it puts the ACCELERATION-LIMITING circuit into operation. The acceleration-limiting circuit becomes a part of the amplifier biasing system, and reduces the sensitivity of the amplifier. The net result of the *K*4 action is that control is transferred to the COARSE C.T.; but acceleration is limited by the reduced amplifier sensitivity.

When the mount comes within 4° of correspondence, the *K*4 relay drops out. This puts the fine C.T. in control again. But since the error is still larger than 1°, the synchronizing aid circuit is in action. Then *K*3 closes to damp the overlarge error signal and decreases the amplifier sensitivity. This prevents a sudden acceleration as the large fine-error signal takes control.

The limit circuit does three things—it opens the *K*1, *K*2 relays to open the amplidyne control fields; it closes *K*5 to desensitize the amplifier; and it sets a spring brake on the power motor. *K*5 also rearranges the amplifier grid circuits to protect the amplifier tubes.

ACCELERATION-LIMITING CIRCUIT

Details of the acceleration-limiting circuit are shown in figure 8–7. Follow the heavy lines to see how it is connected to the converter-amplifier.

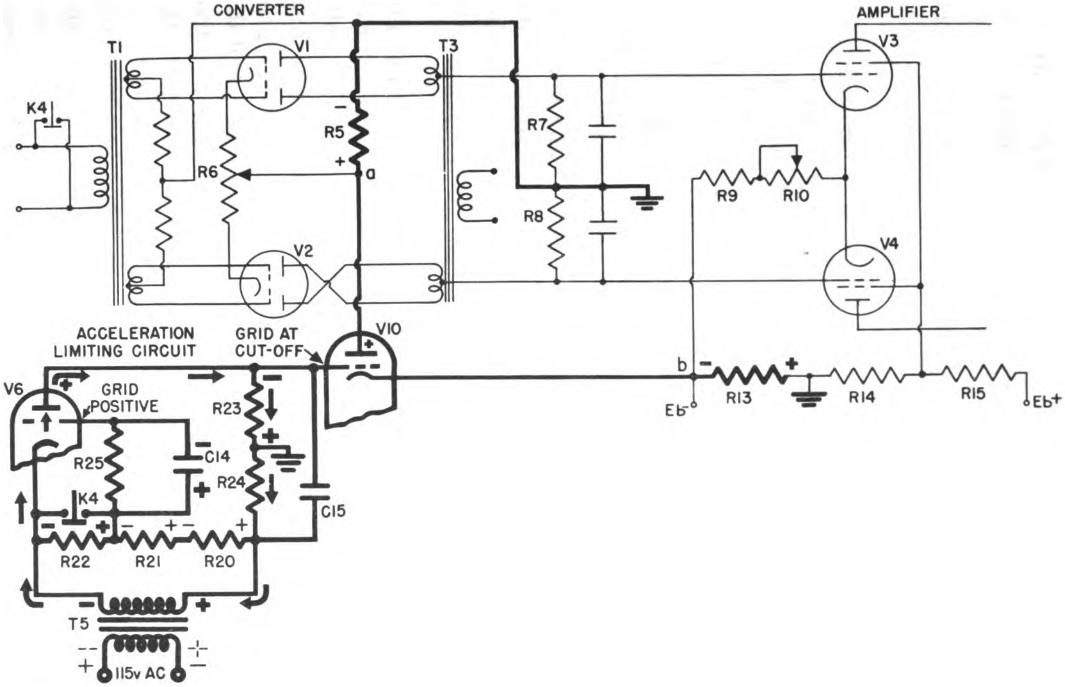


Figure 8-7.—Acceleration-limiting circuit, fine-control.

The *K*4 relays in figure 8–7 are open. That shows that the system is in FINE CONTROL, and that means the acceleration-limiting circuit SHOULD NOT be in action.

Follow the arrows in figure 8–7 which show why the acceleration-limiting circuit is not in action. *R*22 furnishes a positive bias to the *V*6 grid. This means a large *V*6 plate current, which develops a large voltage across *R*23 and *R*24. Notice the polarity of that voltage—*Q*23 biases *V*10 at cutoff.

Now trace the *V*10 grid circuit—grid, *R*23, ground, *R*13, and cathode. Notice how the *R*23 voltage opposes the *R*13 voltage. The *R*23 voltage is strong enough to cancel the *R*13 voltage and keep the *V*10 grid at cutoff. *C*15 filters the *R*23, *R*24 voltage. This steadies the cutoff bias on *V*10.

With *V*10 at cutoff, the acceleration-limiting circuit is entirely out of action—it's disconnected from the converter-amplifier.

The most important thing in figure 8–7 is the action of *Z*25, *C*14. The *R*22 voltage drives the *V*6 grid positive, and the positive grid draws current through *R*25. The resulting *R*25 voltage charges *C*14 which remains charged whenever the system is in fine control.

Figure 8–8 shows the acceleration-limiting circuit going into action. The coarse C.T. is taking control for an error of more than 4°. When *K*4 closes, it shorts out the *R*22 voltage. With *R*22 shorted out, *V*6 loses its positive grid bias and *C*14 discharges through *R*25 and biases the *V*6 grid negative. This negative bias cuts off the *V*6 current and the *R*23, *R*24 voltage falls to zero. This removes the negative bias from *V*10 grid so that *V*10 conducts and connects the acceleration-limiting circuit to the converter-amplifier.

Trace the *V*10 current in figure 8–8 by following the heavy arrows. Notice that *V*10 conducts because *Eb* makes the cathode negative to the plate. The *V*10 current flows through *R*5 reducing the *V*1, *V*2 bias. With a reduced bias, the V1, V2 currents increase. This increases the voltage across *R*7 and *R*8 driving the *V*3 and *V*4 grids more

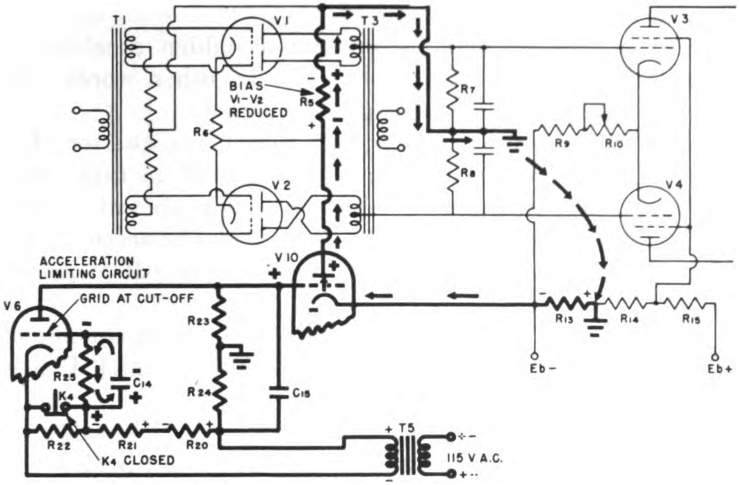


Figure 8–8.—Acceleration-limiting circuit in action.

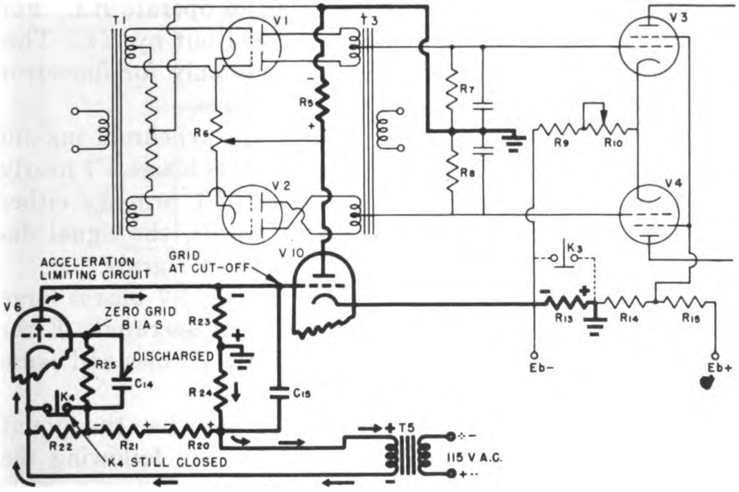


Figure 8–9.—Acceleration-limiting circuit out of action.

negative. The result is that *V3* and *V4* are desensitized because they are nearer to cutoff.

Desensitizing V3 and V4 prevents a sudden acceleration as the coarse signal takes control. In other words, the acceleration is limited for a large error signal.

The *V10* current flows for only about one-quarter of a second because *C14* discharges through *R25* in that time. Then with *C14* discharged, the *V6* bias is ZERO so *V6* again conducts, biasing *V10* at cutoff. This puts the acceleration-limiting circuit out of action by disconnecting it from the amplifier converter.

Figure 8–9 shows the acceleration-limiting circuit out of action again. Notice that *C14* is discharged and *V10* is biased at cutoff.

When the error becomes less than 4 degrees, *K4* will open again, allowing *C14* to charge so that the circuit is all set to limit acceleration for a large-error signal.

SYNCHRONIZING-AID CIRCUIT

The Mk 9 synchronizing-aid circuit amplifies the fine-error signal to operate the *K3* relay. For errors of less than one degree, the fine signal is too small to operate *K3*. For errors above 4°, the fine signal is shorted out by *K4*. This means the synchronizing-aid circuit acts only for fine-error signals between one degree and four degrees.

The heavy lines in figure 8–10 show the synchronizing-aid circuit. Trace the *V7* biasing system—*R38* biases *V7* nearly at cutoff, but the fine signal across the *T1* primary either AIDS OR OPPOSES this bias. In other words, the signal decreases the bias on one or the other of the *V7* grids.

For error signals of less than one degree, *V7* bias is large enough to limit the *V7* current so *K3* is not operated. Error signals of more than one degree reduce the *V7* bias and cause *V7* to pass enough current to close *K3*.

Figure 8–11 shows the limit-circuit action when the mount is in the right limit. Follow the action by following the current arrows.

There are two *K3* relays. The *K3* relay in the synchro-

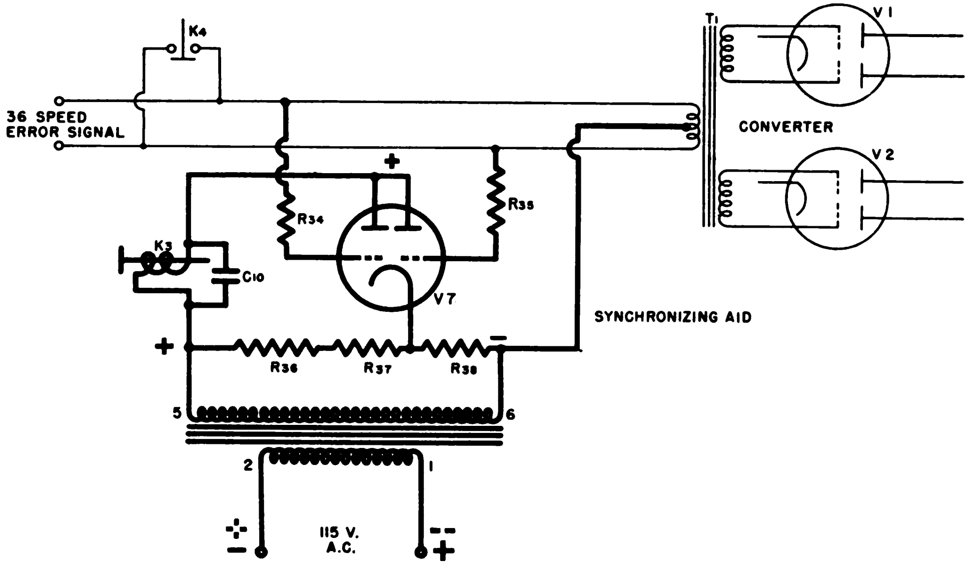


Figure 8–10.—Synchronizing-aid circuit.

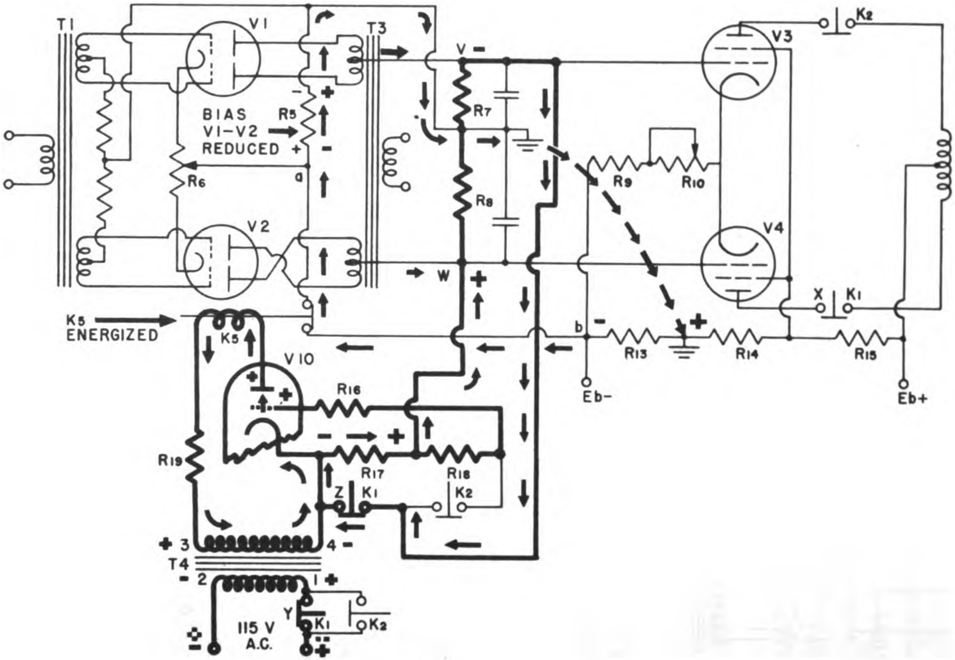


Figure 8–11.—Limit circuit, right limit action.

nizing-aid circuit supplies a large damping voltage to the converter circuit shown in figure 8–10 and the *K*3 relay in the amplifier section of figure 8–9 removes the positive bias from *V*3 and *V*4 by shorting out *R*13. This desensitizes *V*3 and *V*4 and prevents overspeeding for the large FINE-ERROR signal.

LIMIT CIRCUIT

The limit circuit in the Power Drive, Mk 9, opens the amplidyne control fields; it sets a spring brake on the drive motor; and it biases the amplifier grids near cutoff to protect the tubes in the amplifier circuit. See figure 8–11.

When the mount drives into the right limit, the limit switch opens the *K*1 relay coil. The *K*1 relay at point *x* drops out and opens the right-train amplidyne control field. At the same time the left-train control field is still energized. This reverses the amplidyne output and brakes the mount momentarily because the drive motor tries to drive it in left train. There another *K*1 relay at point *y* drops in. This relay energizes the plate circuit of *V*10 (the half of *V*10 not used by the synchronizing-aid circuit). Also, the *K*1 relay at point *z* drops in and this relay puts the converter output across *R*17.

Now, trace these two *K*1 circuits in figure 8–11. Notice how the converter output across *R*17 drives the *V*10 grid positive. *V*10 conducts heavily and energizes the relay *K*5. *K*5 opens the holding circuit of the spring brake, and this sets the brake on the drive motor. At the same time another *K*5 opens the *K*2 relay. When *K*2 opens, it opens the left-train control field. The net result is that both amplidyne control fields are now open and the spring brake is set.

Finally, the *K*5 relay, located just above *V*10 in figure 8–11, puts the *R*13 voltage across *R*5. This action is the same as in the synchronizing circuit, and the results are the same—the grids of *V*3 and *V*4 are driven nearly to cutoff by the increased output of *V*1 and *V*2.

The only reason for cutting off of *V*3 and *V*4 is to prevent a damaging screen grid current. If *V*3 and *V*4 were not

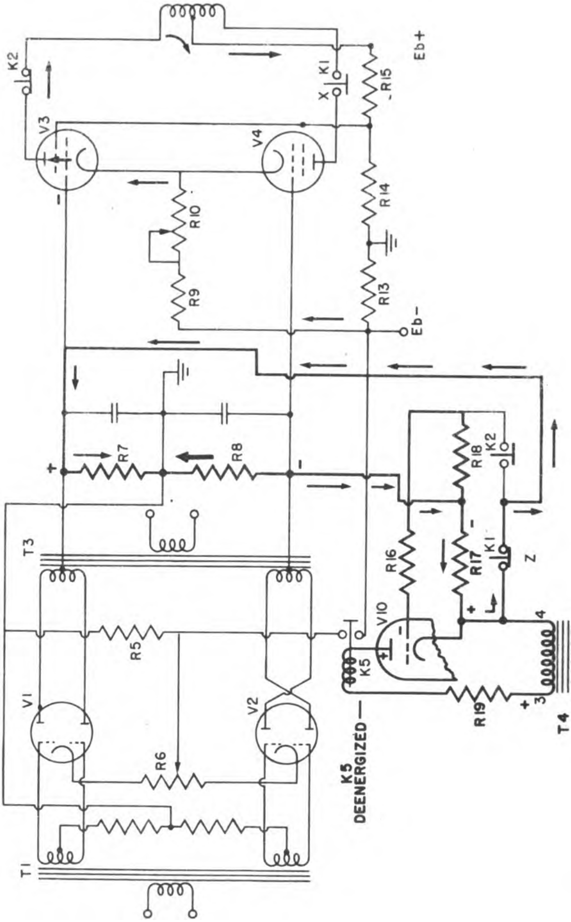


Figure 8-12.—Limit circuit, out of the limit.

cutoff, their screen grids would act as plates because the real plate circuits are opened by *K*1 and *K*2, and the screen grids acting as plates would be burned by the plate current.

Figure 8–12 shows the limit circuit as the mount PULLS OUT of the limit.

A left-train signal at *T*1 (fig. 8–12) is the first step in pulling out of the right limit. The left-train signal increases the *V*2 current and decreases the *V*1 current. This causes *R*7 and *R*8 to reverse the polarity across *R*17, and the reversed *R*17 voltage biases *V*10 at cutoff. With *V*10 at cutoff *K*5 is deenergized and the contacts open.

When *K*5 opens, the spring brake is released and *K*2 is closed. With *K*2 closed the left-train signal energizes the drive motor and pulls the mount out of the right limit. As the mount leaves the stop, *K*1 at point *X* closes, and *K*1 at points *Y* and *Z* opens. The mount is again ready for normal operation.

For left limit operation everything is the same except that the *K*2 circuits are operated first and *R*18 controls *V*10.

QUIZ

1. An amplidyne drive is used in the Gun Director, Mk 38, for the
   a. train, elevation, and cross-level drives
   b. cross-level drive only
   c. elevation drive only
   d. train drive only
2. The stabilizing circuit of the Gun Director, Mk 38, differs from the stabilizing circuit of the Mk 37 in that the Mk 38 stabilizing circuit
   a. combines the feedback voltages before they are put into the converter
   b. feeds the feedback voltages directly into the converter
   c. has no quadrature winding
   d. has no provision for preventing jitter
3. The purpose of *R*11 and *R*12 in the converter circuit of the Mk 38 is to
   a. bias *V*1 at cutoff
   b. limit grid current
   c. hold the grids at midpoint of the grid-characteristic curve
   d. balance the plate currents in *V*1

4. A synchronizing circuit must be used with the Mk 38 train drive because the
   a. low frequency feedback signals are not fed into the converter
   b. train drive circuit has no limiting circuits
   c. output of the antihunt circuit is small
   d. train drive circuit is controlled by a single signal

5. In the synchronizing circuit of the Mk 38 the main plates in the gas-filled tubes conduct when the tubes are fired by the
   a. starter currents
   b. current through *TS*31
   c. stabilizing voltages
   d. voltage across *C*4

6. In the synchronizing circuit of the Mk 38, what determines which gas-filled tubes fires when the error signal is large?
   a. Phase of the error signal at *T*4
   b. Polarity of the current through *TS*31
   c. Strength of the stabilizing voltages
   d. Strength of the error signal at *T*1

7. Which of the following potentiometers in the stabilizing circuit of the Mk 38 controls the setting of the firing point of *V*5 and *V*6?
   a. *R*13
   b. *R*14
   c. *R*15
   d. *R*16

8. The purpose of the *R*17, *TS*31 combination in the synchronizing circuit of the Mk 38 is to
   a. filter high-frequency error signals from the input circuit
   b. filter low-frequency error signals from the input circuit
   c. attenuate large error signals
   d. prevent the development of parasitic oscillations

9. The 40-mm quad mount tends to overdrive when it overspeeds because it is
   a. controlled by both a fine and coarse error signal
   b. carried beyond correspondence by its great weight
   c. geared for high turning speed
   d. driven by the amplidyne power drive

10. Overspeeding on large error signals must be prevented without decreasing the
    a. sensitivity of the amplidyne to small error signals
    b. response time to large error signals
    c. starting torque of the drive motor
    d. speed with which the mount is turned

11. Which of the following special circuits in the Mk 38 is operated by the fine-error signal when the error becomes greater than 1°?
    a. Coarse relay
    b. Accelerating limit
    c. Limit
    d. Synchronizing aid
12. The acceleration-limiting circuit of the Power Drive, Mk 9 reduces the sensitivity of the amplifier by
    a. reducing the plate voltage on the amplifier tubes
    b. biasing the amplifier tubes near cutoff
    c. driving the amplifier tubes toward saturation
    d. decreasing the resistance in the cathode circuit of the amplifier tubes
13. The synchronizing-aid circuit of the Power Drive, Mk 9 is in operation only when the error is
    a. less than 1°
    b. more than 1° but less than 4°
    c. more than 4° but less than 10°
    d. more than 10°
14. When the mount has been driven into left limit and the limit circuit has been operated, *K*5 of that circuit is de-energized by the
    a. bias across *R*18
    b. bias across *R*5
    c. plate current of *V*10
    d. operation of *K*2
15. Which of the following relays in the limit circuit is operated first when the mount drives into left limit?
    a. *K*1
    b. *K*1 and *K*2 operated simultaneously
    c. *K*2
    d. *K*5

CHAPTER 9

BALLISTICS AND TABLES

Ballistics is the science of the motion of projectiles. It is divided into two branches, INTERIOR and EXTERIOR ballistics. Interior ballistics is that branch of the science which treats of the motion of the projectile while in the gun. The INITIAL VELOCITY, i. e., the speed of the projectile at the time it leaves the muzzle of the gun, is a result of the various forces which are involved in the general term, interior ballistics. Exterior ballistics pertains to the projectile after it leaves the gun. Initial velocity is the one value that is common to both interior and exterior ballistics.

Exterior ballistics starts with a projectile traveling at a known speed and in a known direction. This direction, for all practical purposes, is the direction of the center line or axis of the gun barrel. From then on you have no further control over where the projectile goes; forces other than the gun and the director take over. But it is important to find out where it is going to go under the affect of these forces because if you do, you will know how to position the gun barrel to make the projectile go where you want it to go. For example, if you know that the projectile is going to curve to the right, you will train the gun to the left. If you know the projectile is going to curve downward, you will elevate the gun.

In other words, you will solve the fire-control problem. All the gear—the directors, the synchros, the servos, the rangekeepers, the integrators, the rangefinders, the power drives—have just one purpose: to find the right position for the gun barrel to make it fire the projectile where you want it—and to put the gun in that position.

HYPOTHETICAL CASE

If you were far enough in outer space and picked up a projectile and then let go of it, the projectile would stay where you put it. Out in space objects have little or no weight—there are no bodies close enough to exert an appreciable gravitational pull.

So how are you going to lay the gun? The answer is provided by one of the fundamental laws of physics—Newton's first law of motion. This law states that any moving body will continue to move in a straight line at the same speed until something interferes with it. When the projectile shoots out the muzzle of your "space" gun at a speed of 2,700 feet per second, there is nothing to interfere with it. It will simply continue to travel at this speed indefinitely until it hits something.

That would make fire control pretty easy. You would not have to worry about range, deflection, sight angle, superelevation, and the many other factors that are involved in laying a gun on a ship on the surface of the earth. You would just sight the gun barrel at the target and press the firing pedal. If the enemy is on the line of the gun axis and stays there, he will get hit no matter how far away he is.

PROBLEM OF WEIGHT

But let's get down to earth where things are not so easy. Here bodies HAVE weight, which means that if you lift a projectile and let go of it, it will fall. The surprising thing about falling objects is that, all objects fall at the same speed. This fact was first discovered by the Italian astronomer, Galileo, about 1600. He dropped several objects of different weights from the top of the Leaning Tower of Pisa and found that they all hit the ground approximately together.

A falling body, generally speaking, falls faster and faster the longer it falls. If it were not for air resistance, this would be precisely true. Each second that it falls it gains a definite amount of speed—about 32.2 ft/sec. This change of velocity, or acceleration, is the same for any body falling to the earth. It is usually written as g.

FIRE CONTROL IN A VACUUM

Suppose you could line up the axis of a gun on earth in a vacuum and fire it straight at a target. As before, the projectile will continue to travel in the same direction and same speed unless something interferes with it. But now something does, the weight of the projectile.

As soon as the projectile leaves the barrel it starts to fall, and since all bodies fall in exactly the same way, the projectile shot from the gun falls at the same speed and same distance in any time interval. The only difference is that it is traveling forward and falling at the same time. The projectile, you see, has two different motions, one forward and one down, as shown in figure 9-1.

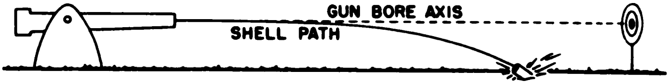


Figure 9-1.—Weight of the projectile.

If the projectile is going to curve downward when you fire the gun, you must elevate the gun. But the question is, how much? Suppose you elevate the gun above the horizontal by some angle, *Eg*, as shown in figure 9-2. This angle, the gun elevation above the horizontal, is known in ballistics as the ANGLE OF DEPARTURE, and the direction of the gun axis is called the LINE OF DEPARTURE or the line in which the projectile "departs" from the gun.

With the gun elevated the projectile will still have two motions, a motion in the line of departure at a speed equal to the initial velocity (I. V.), and a falling motion straight down at a constantly accelerating speed. Just after the projectile leaves the gun it will be falling quite slowly as most of its motion will be upward and forward in the line of departure. As it travels farther, it will fall faster until the falling speed equals the upward speed in the line of departure. The point at which this occurs will be the highest point of the projectile's path. As the projectile continues to fall, gravity will be pulling it down faster than its momentum carries it upward so its path will curve downward, more and more steeply, until finally it hits the ground.

The distance from the gun to the point where the projectile hits the ground is the RANGE of the gun and this range will change with any change in the angle of departure. You can see why this is true. When the line of departure is tilted upward, the projectile's initial velocity tends to carry it higher and the projectile has further to fall as it has a chance to go farther forward.

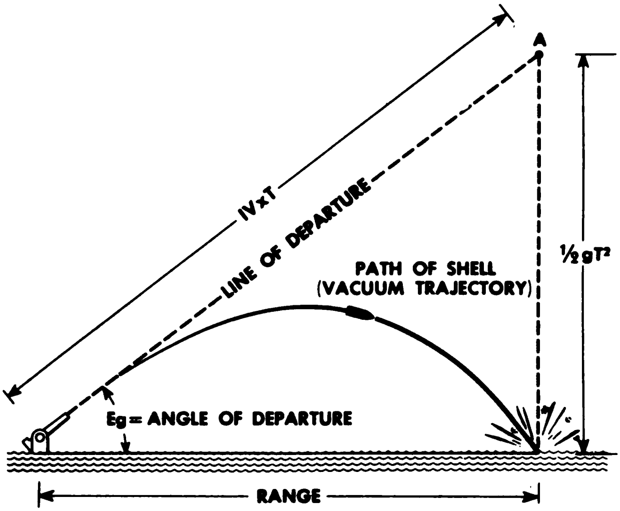


Figure 9–2.—Elevating the gun.

But something else is happening too. As the gun elevates, the projectile is given more upward movement, but it is also given a lesser forward movement. If you elevate the gun above 45°, the time the projectile is traveling will continue to increase but the forward movement will be so much slower that, even in the longer time the projectile will not go as far. Obviously, if you shoot straight up, the range will be zero. Maximum range would be obtained in a vacuum at an elevation of approximately 45°. Typical paths, or trajectories, in a vacuum are shown in figure 9–3.

The range for any particular elevation of the gun can be figured out since the projectile has two motions, the I. V. and the falling motion. You assume that the projectile travels in its line of departure for *t* seconds to reach point *A* in figure 9–2, and that it is stopped at that point and allowed to fall freely for the same number of seconds. The point it then reaches is the same point it would have reached traveling in its actual trajectory for *t* seconds. You can see how this works by referring to figure 9–2. The projectile will reach its full range at the instant when the distance traveled upward as a result of the initial velocity equals the distance fallen.

By this reasoning you could work out a simple formula which would tell you the range of a projectile for any values of I. V. and *Eg*, but the formula would be true only for vacuum trajectory, since in a vacuum trajectory there is no air resistance.

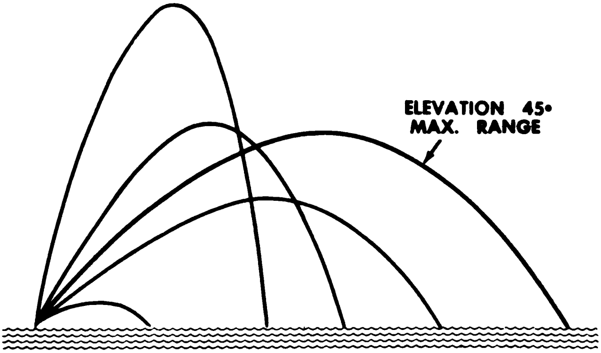


Figure 9–3.—Trajectories in a vacuum.

There are several interesting things you should notice about the vacuum trajectory. Its shape is the curve known in geometry as a parabola. The highest point of the curve is in the middle, and it is symmetrical. The angle at which the projectile lands, called the ANGLE OF FALL, is equal to the angle of departure. And the speed at which it lands, called the STRIKING VELOCITY, equals the I. V.

Air trajectory is determined by making necessary modifications to the vacuum trajectory.

EFFECTS OF AIR

When the projectile is traveling through air instead of a vacuum, the air makes the projectile take a different path from the one it would follow in a vacuum.

The effect of air is to resist the motion of any body passing through it. That is, when any body is moving through the air, the air will set up a force pushing backward in the line of motion of the body. This force keeps slowing the movement of the body and a certain amount of speed is lost during each second of its flight.

A peculiar thing about air resistance is that it increases rapidly as the speed of the body increases. Roughly, when the speed doubles, the retardation of the projectile becomes more than four times as great. Thus, if a projectile traveling at 1,000 ft/sec were retarded 100 ft/sec every second, a projectile traveling 2,000 ft/sec might be slowed as much as 400 ft/sec every second.

With a little thought you can see what air resistance does to the shape of the vacuum trajectory. When first fired, the forward velocity of the projectile is much greater than its velocity up or down. Then the longer the projectile travels through the air, the slower it goes. Shortening of the trajectory will be more noticeable at the far end. The high point of the trajectory will not be at the middle as it is in a vacuum, but will be nearer the point of impact than it is to the gun.

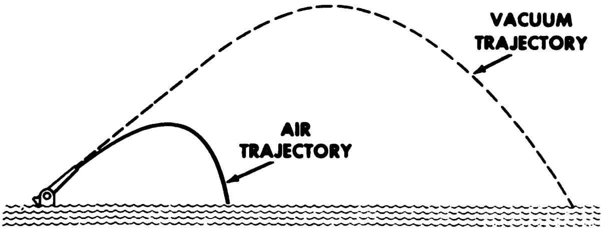


Figure 9–4.—Vacuum and air trajectories.

In figure 9–4, you can see how the trajectory of a projectile fired in air differs from that of a projectile fired at the same angle of departure in a vacuum. Notice that the range of the projectile is much less than the range in a vacuum.

In order to give a projectile the same range in air that you would get in a vacuum, you would have to elevate the gun much farther, as shown in figure 9–5. And if the elevation were already set for maximum range (45°), an equal range could not be achieved.

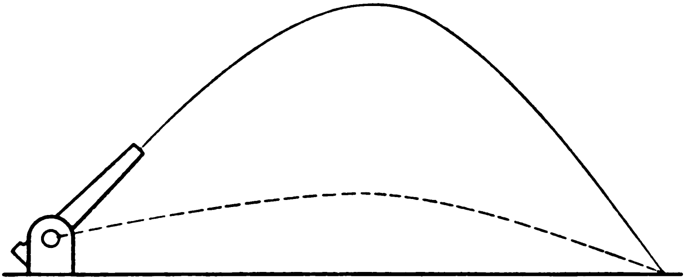


Figure 9–5.—The gun must be elevated farther in air.

One other thing affecting the trajectory is the DENSITY of the air. Dense air will slow the travel of a projectile more than thin air and this complicates the problem quite a bit. Air density depends on temperature and barometric pressure and these values are changing all the time. Moreover, the density is less at points high in the air than it is at sea level. Since the trajectory rises high into the air for a long-range shot, the projectile will be retarded less during each second that it is at the high point of the trajectory than when it is at the low points.

Another thing that affects the shape of the trajectory is the WEIGHT of the projectile. The heavier the projectile, at the same I. V., the less it is affected by the air resistance.

The SHAPE of the projectile also makes a difference. Obviously, the bigger around the projectile is, the more air will push against it. A pointed nose makes it easier for the projectile to push its way through the air and reduces resistance. Boattailing or tapering the after end of the projectile reduces the drag resulting from air turbulence behind the projectile, which also reduces resistance.

The effect on the air resistance resulting from the shape of the projectile is expressed by a quantity called the COEFFICIENT OF FORM. The data for such a drag coefficient or resistance curve are available from measurements obtained by actual experimental firings of the standard projectile at the Naval Proving Ground.

FINDING THE RANGE OF A PROJECTILE

You have learned that when a stationary gun fires in air, the range attained will depend on the following things:

1. The initial velocity.
2. The elevation above the horizontal.
3. The density of the air.
4. The weight of the projectile.
5. The shape of the projectile.

It is possible to work out mathematically the shape of the air trajectory for different values of the above quantities. The computation is quite difficult and is performed by men familiar with higher mathematics at the Proving Ground. When the calculation has been made, it is possible to work out tables giving the range, time of flight, and maximum ordinate of the trajectory for different values of the above quantities.

The next step is to simplify the tables by taking a naval gun and substituting its values into the range tables. For example, the 5″38 is designed to have an initial velocity of 2,600 ft/sec and the weight of the standard projectile is 54 pounds. These values are substituted into the tables, and the shape of the standard projectile is put into the tables by giving the right value of the coefficient of form.

Finally, a STANDARD ATMOSPHERE is arbitrarily assumed. The standard used provides for a temperature at sea level of 59° F. and a barometric pressure of 29.53 inches. The standard also assumes that the air density decreases as you go higher in the air according to a standard formula.

By this method it is possible to determine the values of range, time of flight, and maximum ordinate when projectiles are fired from a particular gun at different angles of departure, provided the conditions are standard.

These values have been tabulated for easy reference in a

RANGE TABLE for each particular gun. A portion of the range table for a 5"38 gun firing AA common projectiles is shown in figure 9–6.

As you can see, a great deal of useful information is included in a range table.

Using the Range Table

Notice that column 1 of the range table tabulates a series of ranges in 100-yard steps. The page illustrated runs from 7,000 yards to 9,000 yards. The entire range table for this gun runs from 1,000 yards to 18,200 yards.

Column 2 gives the angle of departure of the gun barrel for each range in degrees and minutes, while column 2a gives the same angle in minutes, i. e., 2° equals 120 minutes, etc. Column 2a is included because the sight angle scales of modern guns are usually calibrated in minutes rather than in degrees.

Suppose you want to hit a target 8,100 yards away. In column 1 you will find 8,100 yards. Opposite 8,100 yards in column 2 you will find that an angle of departure of 6°29′.0 is needed to get this range. This angle of departure is set on the gun and you are all ready.

Remember that the range tables are constructed based on the assumption of standard I. V., standard air density, and standard projectile weight and shape, so if conditions are not standard, you will have to make allowances or corrections for them.

EFFECT OF AIR DENSITY

Any variation of air density from the standard will have to be corrected. The chances are that the air density, when you fire, has some different value than standard. A value of air density is obtained by the ship's aerologist and furnished to the gunnery department in the form of PERCENTAGE VARIATION from the standard density. The air density varies with different altitudes and the effect of the density depends on whether you are firing long or short range. In long range most the trajectory is in the thin upper air. This requires the use of an average value, called BALLISTIC DENSITY, for that range.

Now look at column 12 of the range table. It shows the error which will be produced if the average air density is 10 percent less than standard density. If the density is less, the resistance to the movement of the projectile will be less, and the projectile will go farther. In column 12, opposite 8,100 yards in the range column, you will find a value of 352 which means that, if you set the angle of departure of 6°29′ into the gun and air density is 10 percent below standard, you will overshoot the target by 352 yards.

Now suppose the density were only 8 percent low. Then the error will be 8/10 of 352 yards or an error of 280 yards. Since you will be shooting over, you will have to subtract this 280 yard error from your original range of 8,100 yards which leaves you 7,820 yards. Referring to column 2 of your range table for 7,820 yards, you find your new angle of departure to be 6°03.1′.

In case there is no aerologist aboard to give you a value of ballistic density, you can work out an approximate air density correction by means of a graphic device called a nomogram. An air density nomogram is included in most range tables and one is shown in figure 9–7.

Using the Air Density Nomogram

To use the nomogram, lay a ruler between the point on the temperature line corresponding to present air temperature and the appropriate point on the barometer reading line, and make a mark at the point where the ruler crossed the vertical line labeled SUPPORT D. Now lay the ruler between this point and a point on the line marked range (R) for high ELEVATIONS OR RANGE (*R*) FOR LOW ELEVATIONS. Mark the spot where the ruler crosses the vertical line marked ERROR IN YARDS.

The spot where the ruler crosses the vertical line marked ERROR IN YARDS is the error in range due to a nonstandard air density. Make a correction to range-table range to compensate for this error and get a revised value of angle of departure.

INITIAL VELOCITY=2600 F.S. WEIGHT OF PROJECTILE=54 POUNDS.

Range	Angle of elevation			Increase in angle of elevation for 100 yards increase in range	Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high
1	2		2a	2b	3		4	5	6	7
Yards	°	′	Minutes	Min.	°	′	Seconds	F. S.	Yards	Yards
7000	5	00.1	300.1	7.4	8	14	12.06	1232	22.8	46
7100	5	07.5	307.5	7.5	8	30	12.31	1220	23.8	45
7200	5	15.0	315.0	7.6	8	46	12.57	1208	24.8	43
7300	5	22.6	322.6	7.8	9	02	12.83	1197	25.8	42
7400	5	30.4	330.4	8.0	9	19	13.09	1186	26.9	41
7500	5	38.4	338.4	8.1	9	36	13.36	1175	28.0	40
7600	5	46.5	346.5	8.2	9	53	13.63	1165	29.1	39
7700	5	54.7	354.7	8.4	10	11	13.90	1155	30.3	37
7800	6	03.1	363.1	8.5	10	29	14.17	1146	31.5	36
7900	6	11.6	371.6	8.6	10	47	14.45	1137	32.7	35
8000	6	20.2	380.2	8.8	11	06	14.73	1128	34.0	34
8100	6	29.0	389.0	9.0	11	25	15.01	1119	35.3	33
8200	6	38.0	398.0	9.2	11	44	15.29	1111	36.6	32
8300	6	47.2	407.2	9.3	12	04	15.58	1103	38.0	31
8400	6	56.5	416.5	9.5	12	24	15.87	1095	39.4	30
8500	7	06.0	426.0	9.6	12	44	16.16	1088	40.8	30
8600	7	15.6	435.6	9.8	13	05	16.45	1081	42.3	29
8700	7	25.4	445.4	10.0	13	26	16.75	1074	43.8	28
8800	7	35.4	455.4	10.1	13	47	17.05	1067	45.4	27
8900	7	45.5	465.5	10.3	14	09	17.35	1060	47.0	26
9000	7	55.8	475.8	10.4	14	31	17.65	1054	48.6	26

Figure 9–6.—Range

LENGTH OF PROJECTILE=4.15 CALIBERS. RADIUS OF OGIVE=5.25 CALIBERS.

Maximum ordinate 8	Change of range for variation of +10 feet per second initial velocity 10	Change of range for variation of -1 pound in weight of projectile. 11	Change of range for variation in density of air of -10 per cent 12	Change of range for wind component in plane of fire of 10 knots 13	Change of range for motion of gun in plane of fire of 10 knots 14	Change of range for motion of target in plane of fire of 10 knots 15	Deviation for lateral wind component of 10 knots 16	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots 17	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots 18	Change in height of impact for variation of 100 yards in sight bar 19
Feet	Yards	Yards	Yards	Yards	Yards	Yards	Yards	Yards	Yards	Feet
590	37	5	275	31	37	68	22	46	68	43
615	37	5	282	32	37	69	23	46	69	44
640	38	4	289	33	37	71	24	47	71	46
670	38	3	296	34	38	72	24	48	72	47
700	38	2	303	35	38	74	25	49	74	49
730	39	1	310	36	38	75	26	49	75	50
760	39	0	317	38	38	77	27	50	77	52
790	39	− 1	324	39	38	78	27	51	78	54
820	40	− 2	331	40	39	80	28	52	80	55
855	40	− 3	338	42	39	81	29	52	81	57
890	40	− 4	345	43	39	83	30	53	83	59
925	40	− 5	352	44	39	85	31	54	85	61
960	40	− 6	359	46	39	86	32	54	86	63
1000	41	− 7	366	47	39	88	33	55	88	64
1040	41	− 8	373	48	40	89	34	55	89	66
1080	41	− 8	380	50	40	91	35	56	91	68
1120	41	− 9	386	51	40	92	36	56	92	70
1160	42	−10	393	53	40	94	37	57	94	72
1205	42	−11	400	55	40	96	38	58	96	74
1250	42	−12	406	56	40	97	39	58	97	76
1295	42	−13	413	58	40	99	40	59	99	78

table for a 5″ gun.

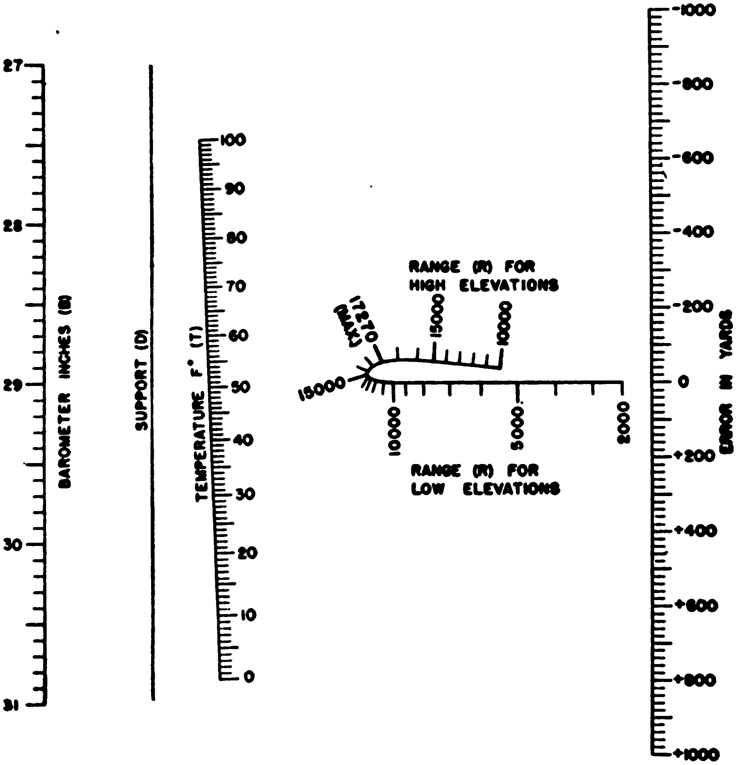


Figure 9–7.—Air density nomogram.

The use of the nomogram is more accurate than results obtained from using column 12 with surface observations, as the nomogram takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.

Changes in Initial Velocity

The range table is based on an I. V. of 2,600 ft/sec. This is the initial velocity that the gun is designed to have, but few guns in the fleet actually develop their designed velocities. There are two reasons for the lower initial velocities obtained in actual firing.

One reason is the wear of the gun barrel. Every time the gun is fired the inside of the barrel is slightly worn away, so that the bore becomes enlarged. This reduces the pressure behind the projectile and lowers the initial velocity.

Records are kept of the number of times a gun is fired. In this record a round of target ammunition using a reduced powder charge is counted as an equivalent fraction of a service round. The total of service rounds plus target rounds counted in this way is called EQUIVALENT SERVICE ROUNDS. Curves have been worked out experimentally for each type of naval gun showing the I. V. loss to be expected after any number of equivalent service rounds fired.

The same thing may be accomplished by measuring the enlargement of the bore with a STAR GAGE. Curves are available showing the I. V. loss for any amount of enlargement. For example, if the bore of a 5″38 gun Mk 12 is enlarged 0.04 inches, the I. V. will be reduced about 28 ft/sec. This is more accurate than counting the rounds fired. The usual procedure is to star-gage guns periodically to get a value of I. V. loss, and then keep track of rounds fired between star gagings.

The second reason for lower initial velocity is the change in the condition of the powder. With modern manufacturing method the chemical composition of smokeless powder does not vary to any great extent, but powder has a different amount of strength at different temperatures. The warmer the powder, the more powerful it is.

Naval guns are designed to obtain standard I. V. when the powder has a temperature of 90° F., and every degree of variation from this standard temperature will change the I. V. by 2 ft/sec. For instance, if the powder being used has a temperature of 80° F., you know at once that the I. V. will be 20 ft/sec less than the rated value. Since magazine temperatures are supposed to be kept as low as possible, this factor will usually reduce I. V. and powder temperature changes slowly, the average magazine temperature for the past several days should be used.

Combining these factors, erosion and powder temperature, you will get a figure for the total change in I. V. from the standard conditions.

Column 10 of the range table gives you the change in range for an increase of 10 ft/sec in I. V. Suppose the figures on gun erosion and powder temperature indicates an I. V. loss of 38 ft/sec. The range is still 8,100 yards. You will find in column 10, opposite this range, a value of 40 yards. To find the effect on the range with a 38 ft/sec I. V. loss, multiply 40 times 38/10, obtaining 152 yards. This means that if you use the angle of departure given by the range table for 8,100 yard range, you will under shoot by 152 yards. Obviously, if you are falling short, the thing to do is ADD A SPOT.

Projectile Weight

Another assumption that was made in computing the range table was that the weight and shape of the projectile were standard. However, in case it should be necessary to fire a projectile of nonstandard weight, column 11 of the range table gives the change in range to be expected if the projectile is reduced in weight by one pound.

Finding Gun Range

So far you have considered each of the errors in range separately, but in practice, all errors will be combined. Thus, in the previous examples, the variation in air density was causing an error of 280 yards over, while variation in I. V. was causing an error of 152 yards short. The combined effect is an error of 128 yards over, or about 100 yards over. An over error requires a down correction, so you find the angle of departure corresponding to a range of 8,100—100= 8,000 yards.

The way the correction is applied is important as the correction will be equal in amount but opposite in sign to the error. In other words, a SHORT ERROR requires an UP or ADD CORRECTION, while a LONG ERROR requires a DOWN or DROP CORRECTION. The total correction is called the GUN BALLISTIC IN RANGE. The resulting corrected range is known as ADVANCE RANGE.

Drift

So far you have found out how to compute the angle of departure using a range table. So you line up the gun on the target, elevate to the proper angle and fire, scoring a clean miss at that range. Why?

Every projectile fired by a Naval gun drifts off to the right as it travels through the air, due to the rifling of the bore.

Figure 9–8 shows the effect of drift on the projectile while it is in flight. Notice that the drift increases with range, but do not confuse this motion with the movements caused by wind. Drift occurs whether there is any wind or not and drift is always to the right in any gun with right-hand rifling which gives a clockwise spin to the projectile.

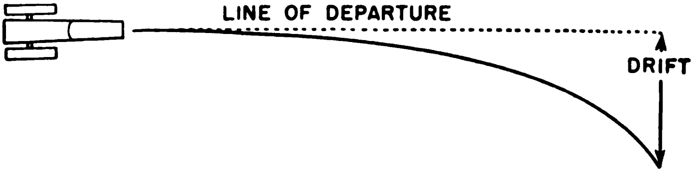


Figure 9–8.—Effect of drift.

The reason naval guns are always rifled is that the gyroscopic action of the spinning projectile keeps it pointing almost exactly along its trajectory. This prevents the projectile from tumbling in the air and weaving around. It also insures that the projectile will land point first. In addition to this useful effect, the gyroscopic action causes the harmful effect of drift. Fortunately, the projectile drifts by a definite amount which can be determined by experiments and tabulated. The amounts of drift to be expected from any trajectory of any naval gun have been tabulated in the range tables.

Column 6 of the range table shows the drift in yards at the target to be expected at any range for a 5″38 gun.

Using the previous range of 8,100 yards, the table shows a drift of 35.3 yards (drift is always to the right). To compensate for this you must deflect the gun barrel to the left by the proper amount.

In order to make this correction, the drift in yards must be converted into an ANGLE IN MILS. Knowing that a mil is the angle which will cause a deflection of 1 yard at a distance of 1,000 yards, this is easy to do.

A 35-yard deflection at 1,000 yards would be equivalent to 35 mils. Therefore, the mils required to produce a 35-yard deflection at 8,100 yards must be 35/8.1 or 4.3 mils.

QUIZ

1. Which of the following is NOT a factor in the science of exterior ballistics?
   a. Wind direction and velocity
   b. Initial velocity
   c. Direction of the axis of the gun barrel
   d. Temperature of the powder
2. On earth the value of *G* is approximately
   a. 3.1416
   b. 32.2
   c. 19
   d. 19.3
3. In ballistics the angle of departure is the angle between
   a. the horizon and the gun barrel axis
   b. the gun barrel axis and the zenith
   c. the gun barrel axis and true north
   d. the gun barrel axis and magnetic north
4. In a vacuum a projectile would follow the path of a
   a. sine curve
   b. circle
   c. parabola
   d. hyperbola
5. Which of the following does not affect the density of the air?
   a. Temperature
   b. Pressure
   c. Wind velocity
   d. Altitude
6. What is the major reason that the striking velocity of a projectile fired on earth is less than its initial velocity?
   a. Air resistance
   b. Rotation of the earth
   c. Gravity
   d. Gyroscopic action of the projectile

7. In the range table for the 5''38 gun, ranges are given in
   a. 50 yard steps
   b. 100 yard steps
   c. 500 yard steps
   d. 1,000 yard steps

8. Under standard conditions, what angle of elevation should be set into a 5''38 gun to hit a target at a range of 8,400 yards?
   a. 6°38.0′
   b. 6°47.2′
   c. 6°56.5′
   d. 7°06.0′

9. Which of the following is a reasonable I. V. loss in a 5''38 gun after 500 rounds have been fired?
   a. 5 ft/sec
   b. 25 ft/sec
   c. 30 ft/sec
   d. 65 ft/sec

10. Drift is always in what direction?
   a. Right
   b. Left
   c. Up
   d. Down

11. What will be the I. V. correction for powder that is at 70° F?
   a. 0 ft/sec
   b. 10 ft/sec
   c. 20 ft/sec
   d. 40 ft/sec

12. Roughly, when the speed doubles, the retardation of the projectile due to air resistance
   a. doubles
   b. triples
   c. quadruples
   d. remains the same

13. In using the air density nomogram, the support is used between the
   a. temperature and barometric scales
   b. temperature and range scales
   c. barometric and range scales
   d. range for high elevation and range for low elevation scales

14. Enlargement of the gun barrel due to wear from firing is called
   a. bourrelet
   b. I. V. loss
   c. erosion
   d. sectional density error

15. **At what approximate elevation is maximum range obtained in a vacuum?**
   - **a.** **25°**
   - b. **30°**
   - c. **45°**
   - d. **60°**

CHAPTER 10

SOLVING WIND CORRECTIONS

At best, corrections to the solution of the fire-control problem for wind are only approximate because not only does the density of air change at different heights, but its motion also changes at various levels. For instance, the wind might be blowing from the north on the surface of the ocean, and from the south at some higher level. Figure 10–1 shows the action of wind that might be encountered at different altitudes.

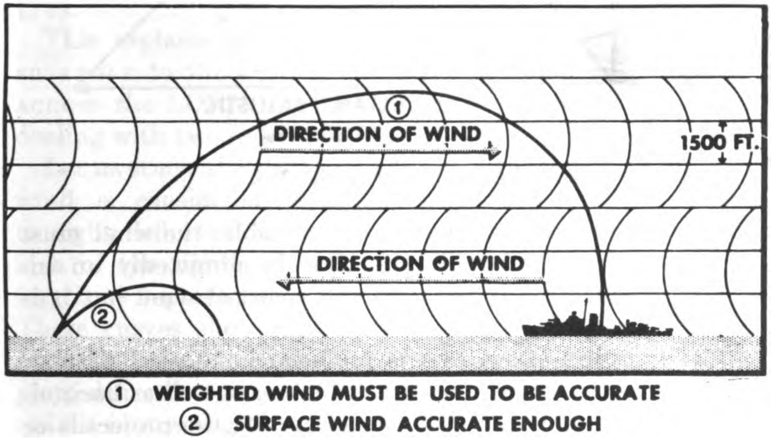

①
DIRECTION OF WIND
1500 FT.
DIRECTION OF WIND
②
① WEIGHTED WIND MUST BE USED TO BE ACCURATE
② SURFACE WIND ACCURATE ENOUGH

Figure 10–1.—Winds at various altitudes.

If there is an aerological party aboard, an investigation of wind conditions at different elevations is made either by aloft observations from an airplane, or by observing the movements of a small balloon. The balloon's course is plotted as it proceeds upward through the 1,500 foot bands shown in figure 10-1 so that wind direction and speed at each level may be evaluated.

After the wind at various levels has been weighted (corrected for air-density changes), a resultant or BALLISTIC WIND is calculated by the method set forth in figure 10-2. A plot of the weighted winds is made to scale, and the over-all wind angle *Bw* and wind speed *Sw* determined. *Bw* is measured in degrees, and *Sw* is measured in knots. These values are then set into the computer to enter into the computations of gun orders.

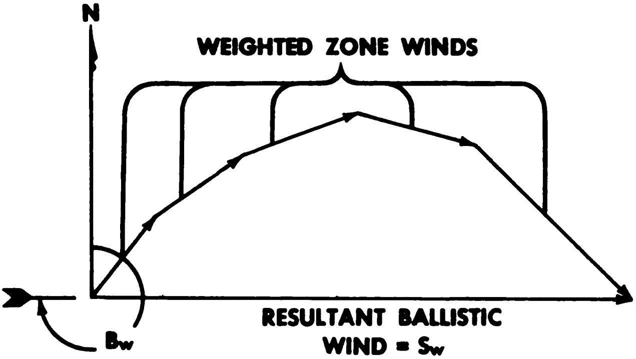


Figure 10-2.—Ballistic wind.

When aloft observations are not possible, the wind must be observed at surface level. This is admittedly an inaccurate way to find the angle and speed of wind but it is better than nothing.

Making wind allowances is further complicated because in the upper air winds blow up and down as well as horizontally. These vertical winds can either lift the projectile or push it down which lengthens or shortens the range. This effect, however, is never considered in fire-control problems.

CROSS WIND

Every ship at sea is influenced by wind blowing from some direction of the compass. This is always a single wind except during a hurricane or some other unusual disturbance. However, in addition to where the wind is blowing from, an important thing is the angle it makes with the line of fire (LOF). It is easy to realize that if the wind is blowing directly ACROSS the LOF it will deflect the projectile one way or the other, and if the wind is blowing IN the LOF it will speed up or slow down the projectile. But the wind is never so accommodating as to blow directly ACROSS or IN the LOF. Instead, it usually blows at some other angle to the LOF.

In solving the problem it is necessary to figure out how much the wind will affect the RANGE and DEFLECTION of the projectile, and to apply the corrections to the gun position accordingly. It is obviously much easier to take a single wind and think of it as two component winds, one blowing ACROSS and the other IN the LOF. Then you can take the cross-wind component and compensate for it by correction to sight deflection (*Ds*), and the range wind component (in LOF) and compensate for it by correction to sight angle (*Vs*).

This explains why, in actual practice, wind blowing at an ANGLE to the LOF is resolved into components IN and ACROSS the LOF, and is corrected for as though you were dealing with two individual winds.

Let us study the two wind components separately. Cross wind is considered separately from drift and is added to sight deflection as an individual correction. To get an idea of the significance of cross wind, look at the curves for three representative guns in the graph of figure 10–3. These curves show the lateral deviation of the projectile in yards for a cross wind of 10 knots. These curves were plotted from column 16 of the range tables for each gun.

It is interesting to notice that the cross wind deflects the projectile more and more as range increases. When the projectile is first fired, it is traveling so fast that the wind has little chance to affect it; but as the projectile starts losing speed the wind begins to deflect it to a marked degree. That is why the curves in the graph sweep upward as the ranges increase. Obviously, the effect of cross wind varies as a function of range rather than directly with range.

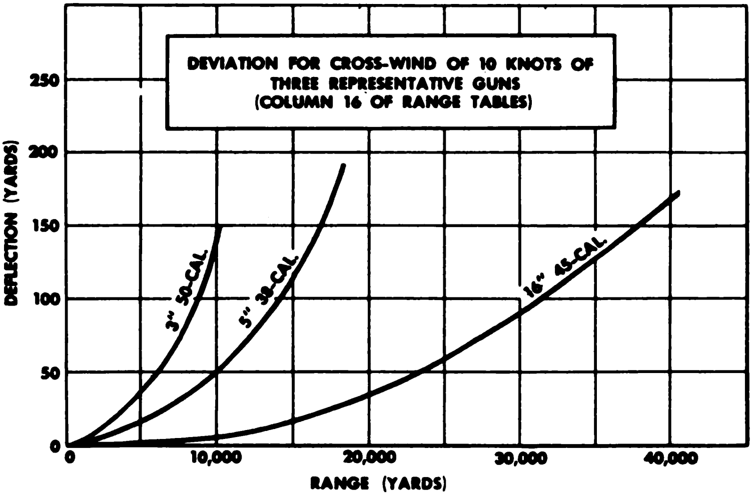


Figure 10–3.—Cross-wind curves.

Looking at it another way, you will see that the amount the projectile deflects will be dependent on two things: wind speed (*Sw*), and the length of time the wind acts on the projectile.

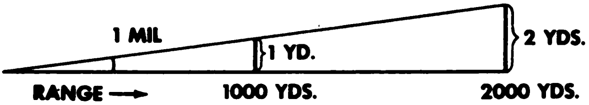
That brings up time of flight (*Tf*). You can see that *Tf* represents the total time the wind acts on the projectile, (the same time it takes for the projectile to reach the target). You will also recall that distance is equal to speed multiplied by time. So your first thought might be that the total deflection of the projectile will be equal to $Tf \times Sw$, and you would be on the right track, but not quite right because the projectile will not deflect at exactly the same speed that the wind is blowing.

The equation can be modified and made correct by multiplying by a small constant (k) whose value (which will vary as the range changes) is dependent on the shape and weight of the projectile. The total deflection distance, as a result of cross wind, will be $k \times Tf \times Sw$.

This formula is not much good unless you modify it a bit more. First, you want to convert it to yards deflection at the target. Then since *Sw* is in knots, you multiply it by

0.563 to convert it to yards per second. Then: $Sw \times 0.563 =$ yards/sec (see fig. 10–4). This can be done in a computer by a gear ratio. For instance, a 2:1 gear ratio reduces the input to one half, which is the same as multiplying the input by 0.5.

YARDS DEFLECTION TO MILS



A MIL IS THE ANGLE WHOSE TANGENT IS $\frac{1}{1000}$

$$\frac{\text{YDS. DEFL.}}{\text{RANGE}} = \text{MILS}$$

KNOTS AND YARDS

KNOT (NAUTICAL MILE/HOUR) = 2027 YDS./HOUR

$$\frac{\text{YDS./HOUR}}{\text{SECONDS/HOUR}} = \text{YDS/SECOND}$$

$$\therefore \text{KNOTS} \times \frac{2027}{3600} = \text{YDS./SECOND}$$

$$\text{OR, KNOTS} \times 0.563 = \text{YDS./SECOND}$$

Figure 10–4.—Mils, knots, and yards.

Next, to get the distance deflection in yards (linear deflection), you multiply *Sw* by time (in this case, *Tf*). Now you have LINEAR DEFLECTION DUE TO WIND EQUAL $k\ (Tf \times Sw \times 0.563)$ YARDS.

This last formula gives you the deflection in yards at the target, but before it can be used to correct sight deflection (*Ds*), it must be converted to angular measure, or MILS. The table in figure 10–4 tells you how. Simply divide yards deflection by range.

The angular deflection due to wind, angular wind deflection, *Dw*, now becomes

$$Dw=\frac{k\times Tf\times Sw\times 0.563}{\text{Adv. Range}}.$$

Notice that you use ADVANCE RANGE, $R2$, the range to the future target position. This corrects the gun in the line of fire, as desired.

Now let us solve the equation for *Dw* by the use of basic mechanisms. Looking over the equation you will immediately decide that the two constants, *k* and 0.563, can be handled by gear ratios also. You may decide to multiply *Tf* and *Sw* in a multiplier, but you still have to divide by $R2$. This can be done by a reciprocal cam and another multiplier so you finally get a setup like the one in figure 10–5.

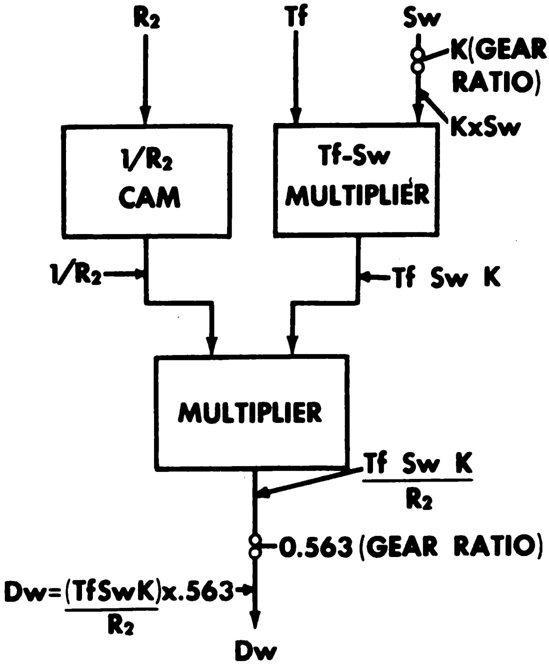


Figure 10–5.—Solving *Dw*.

The arrangement in figure 10–5 would work fine but it would be entirely too bulky and expensive. In order to cut down on the number of computing units, rangekeepers sometimes use a *Tf*/*R*2 which is a combination of the reciprocal cam and *Tf* cam. This eliminates the use of one multiplier to give you the setup shown in figure 10–6.

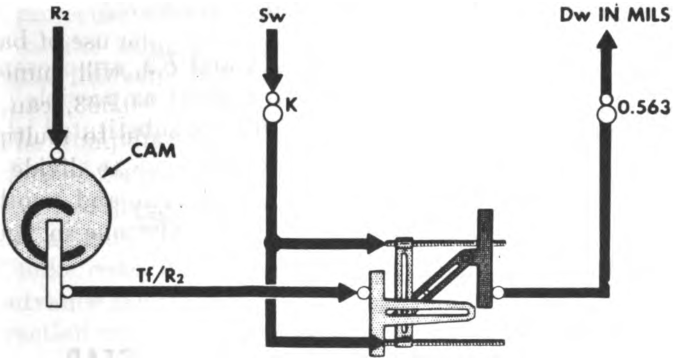


Figure 10–6.—Solving *Dw* with a cam and multiplier.

*R*2 rotates the *Tf*/*R*2 cam; *Tf*/*R*2 is taken from the cam follower to position the input rack of a screw-type multiplier.

Sw (cross-wind speed in knots) is multiplied by *k* in a gear ratio and it positions the screws and input slide of the multiplier.

The position of the output rack is proportional to the product *Tf*/*R*2 × *Sw* × *k*, which is then multiplied in another gear ratio by 0.563 to give you *Dw* in MILS.

Since all ballistics are functions of advance range and advance elevation, many shortcuts are performed to eliminate the use of extra gear. The object is to use the minimum of parts. For instance, rather than computing *Tf*/*R*2 in a cam, it is usually made from other quantities which already exist in the computer. This of course would further simplify the *Dw* computer in figure 10–6.

Another approximate method used to calculate *Dw* in rangekeepers tackles the problem in a little different way. It takes even fewer mechanical devices to solve it. A study of range tables, graphs, and curves has shown designers that both k and $Tf/R2$ vary alike with range. As range increases, they too increase, only faster. It was found that they change in the same proportion as the square root of range, that is, when range quadruples, k and $Tf/R2$ nearly double. Stating it mathematically,

$$k = K1 \times \sqrt{R2}, \text{ and } Tf/R2 = K2 \times \sqrt{R2}.$$

Here two entirely new constants, $K1$ and $K2$, are chosen to make the two expressions as nearly correct as possible.

When these values for k and $Tf/R2$ are substituted in the basic formula ($k \times Sw \times Tf/R2$), you get—

$$Dw = K1 \times \sqrt{R2} \times Sw \times K2 \times \sqrt{R2}.$$

Simplifying this expression gives

$$Dw = K \times Sw \times R2$$

where K is equal to $K1 \times K2$. A single multiplier and a gear ratio like that in figure 10–7 can work this out.

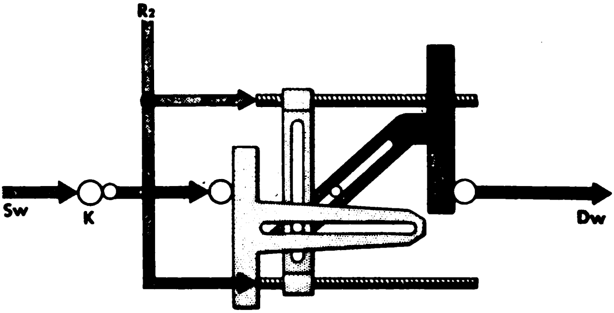


Figure 10–7.—Another method of calculating *Dw*.

The basic idea to get straight is that fire-control instruments use the minimum number of parts, and manufacturers have gone to great lengths to figure out ways of getting a solution from close approximations.

RANGE WIND

The corrections for range wind are similar to those for cross wind and are solved in much the same way. Range wind blows parallel to the LOF, either with or against the motion of the projectile, and gives a forward or backward velocity to the projectile which is independent of other motions. This velocity is equal to $k \times Sw$ and will be moving the projectile throughout the time Tf. The value of k will not be the same at a particular range as for cross wind, because the wind will be acting on different surfaces of the projectile.

The computation for a 10-knot range wind has been performed for you in the range table. When plotted, these values will give you a set of curves similar to those for cross wind in figure 10–3.

Unlike cross wind, corrections for range wind are applied to advance range, as the name might imply. Therefore, the correction would be measured in yards rather than in mils. Fortunately, this simplifies the computation because you have only to multiply by 0.563 (fig. 10–4). It is not necessary to divide by advance range as you must do to determine cross wind.

The correction for range wind then becomes

$$k \times Sw \times Tf \times 0.563 \text{ yards.}$$

But as with cross wind, k varies with range so a value like $K1 - K2/Tf$ is substituted for k in the above formula. This gives range-wind correction $= K1 - K2/Tf \times Sw \times Tf \times 0.563$.

Multiplied out and simplified, you get

$$\text{range-wind correction} = (K1 \times Sw \times Tf - K2 \times Sw)\ 0.563.$$

This equation can be solved with a multiplier, a Tf cam, and a couple of gear ratios as shown in figure 10–8. $R2$ positions the Tf cam to produce the Tf output, which is multiplied by $K1$ in a gear ratio. The output of the gear ratio is $Tf \times K1$, and is multiplied by Sw. The multiplier output is $Tf \times K1 \times Sw$.

At the same time that the multiplier is performing its function, *Sw* is multiplied by *K*2 in another gear ratio and subtracted from the multiplier output in *DF*1. Then the output of *DF*1 is multiplied by 0.563 in a third gear ratio to complete the computation of range wind correction. The correction is added to *R*2 in *DF*2, completing the entire process of range correction for wind.

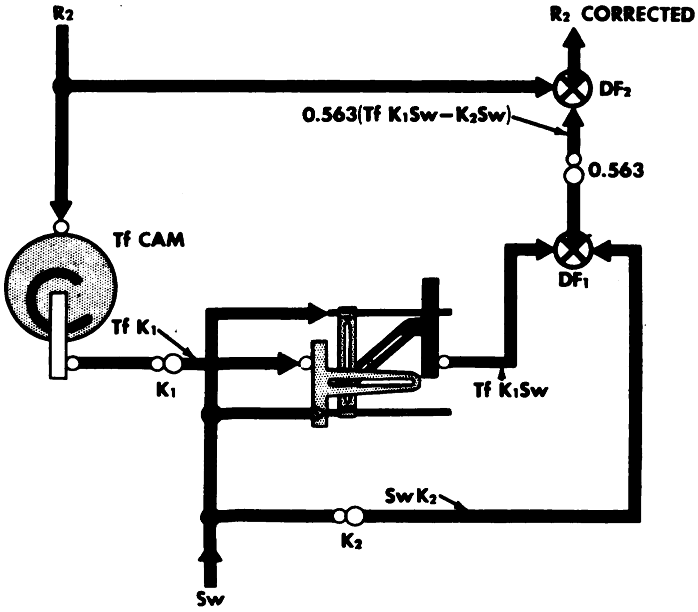


Figure 10–8.—Computing range-wind correction.

Trace out the mechanical arrangement of the parts in figure 10–8, and follow the mathematics solved at each step so that you will thoroughly understand these calculations.

WIND AT AN ANGLE

You have learned about corrections for wind blowing directly IN and ACROSS the LOF, but as has been pointed out, the wind will not be so accommodating as to limit itself to these directions. Instead, it generally comes from a direction that makes an oblique angle with the LOF.

Wind is always described by indicating the direction it is coming FROM. An east wind is blowing FROM the east toward the west. For this reason the direction of the wind is always measured from north in a clockwise direction to the direction from which the wind is coming.

Figure 10–9 shows two wind angles. The first is *Bw*, true WIND DIRECTION. This is the value of wind furnished by the aerological party and is the value you set up on the dials of a rangekeeper.

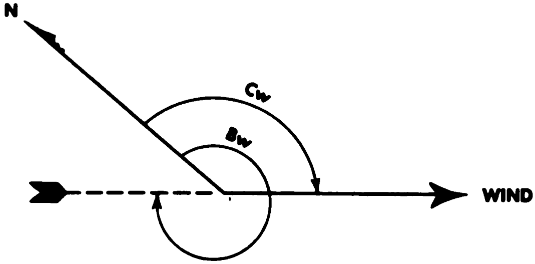


Figure 10–9.—Angles used to compute wind correction.

Bw is not used as it stands in solving the fire-control problem, because quantities such as wind are measured to or from the arrowhead end of a vector. So, instead of *Bw*, a quantity known as WIND COURSE (*Cw*) is used. *Cw* is measured from the direction toward which the wind is blowing as indicated in figure 10–9. A study of the figure will tell you that

$$Cw = Bw - 180$$

or

$$Cw = Bw + 180.$$

The whole idea of the wind problem is to take a wind of known direction and speed and resolve it into components IN and ACROSS the LOS. Then you take these components and proceed as you did with range and cross wind.

Notice that you use the LOS rather than the LOF. For true accuracy you should use the LOF, but since *Ds* is comparatively small in surface fire control, the LOS makes a good enough reference. However, for fast moving air targets, *Ds* is so large that it is necessary to use the LOF.

The angle the wind makes with the LOS is called *Cws* (wind course relative to the LOS), as shown in figure 10–10. It is measured from the arrowhead of the wind vector clockwise to the LOS. To obtain this angle you must know the true direction of the LOS, so you use true target bearing, *B*, measured from north clockwise to the LOS.

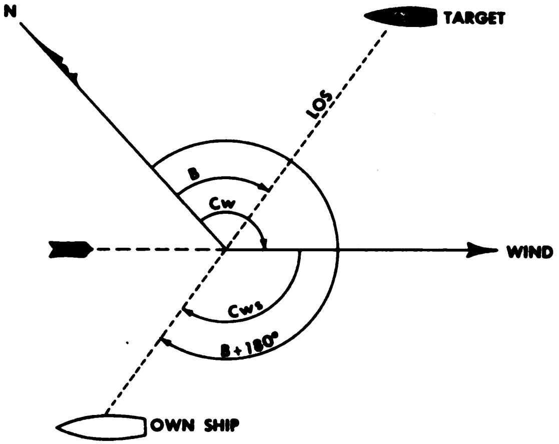


Figure 10–10.—Wind course measured relative to the LOS.

However, *B* is not measured directly, but is made up from *Br* and *Co*. *Br* is measured by the director and *Co* is received automatically from the master gyro compass; they can also be cranked in manually by handcranks. Figure 10–11 shows that *B* is equal to *Br* plus *Co*.

Now that you have the true direction of the LOS, you are ready to find *Cws*. It is computed from *B* and *Cw* as shown in figure 10–11. A study of the figure will tell you that

$$Cws=(B+180)-Cw.$$

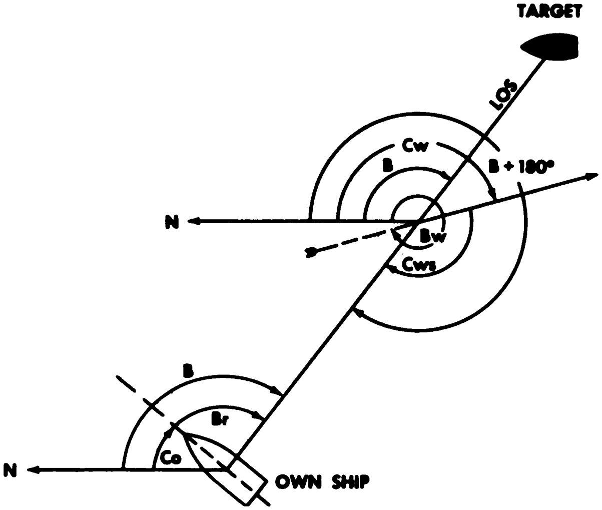


Figure 10–11.—How Cws is obtained.

Cws can be solved in the rangekeeper with a couple of differentials as shown in figure 10–12. *Co* and *Br* are added in *DF*1 to give *B;* and (B+180) and *Cw* are subtracted in *DF*2 to give *Cws*. The 180 constant is put in by slipping the shaft connecting *DF*1 and *DF*2 by 180°.

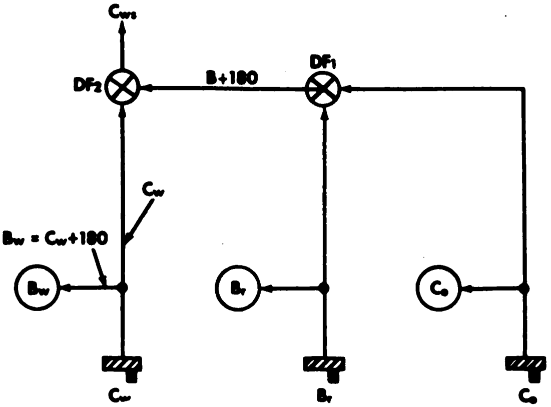


Figure 10–12.—How Cws is computed mechanically.

RESOLVING THE WIND VECTOR

You know the following facts about the wind vector: first its direction (*Cws*) with respect to the LOS, and second its speed, *Sw*. This gives you the setup in figure 10–13. You also know that wind has two effects on the projectile, one of pushing it sideward and the other of shortening or lengthening the range of the projectile. You now resolve the vector into its two right-angle components, *Xw* and *Yw*. *Xw* is the cross-wind component and *Yw* is the range-wind component. From your knowledge of trigonometry you know that these components added will have the same effect as the single vector *Sw*.

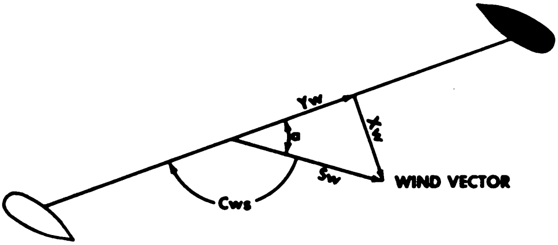


Figure 10–13.—Wind vector.

That leaves only the problem of breaking down *Sw* into its components with the component solver. To calculate the values of the components, notice that

$$Xw = Sw \times \sin Cws$$

$$Yw = Sw \times \cos Cws.$$

For the case shown in figure 10–13, remember that the trigonometric functions of *Cws* are the same as those for angle *a* except for its numerical sign, because *a* is the supplement of *Cws*. Angle *a* equals 180° $-Cws$.

Actually, in the wind problem you do not have to worry about the sign of trigonometric functions because the component solver automatically comes up with the correct sign.

Figure 10–14 shows how the component solver breaks down

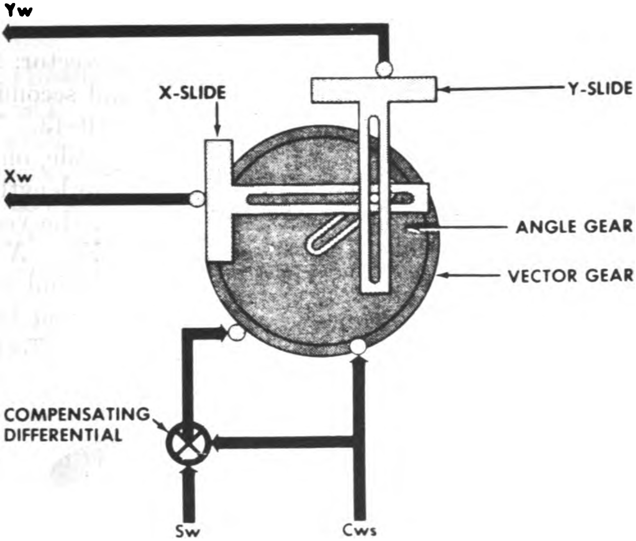


Figure 10–14.—Resolving the wind vector with a component vector.

Sw. *Cws* is the input to the angle gear and *Sw* is the input to the vector gear. Then *Xw* and *Yw* are the slide outputs.

SIMPLIFIED MECHANICAL WIND COMPUTER

Figure 10–15 shows a simplified device for computing wind corrections. It takes the wind vector and resolves it into *Xw* and *Yw* components, and also solves for cross-wind and range-wind corrections. This setup is similar to those used in rangekeepers controlling surface fire.

Notice the inputs to the wind component solver. Wind speed (*Sw*) is inserted by rotating the wind-speed crank until the proper value shows up on the *Sw* dial. *Br* and *Co* are shown as being put in by hand cranks, but these values will come in automatically. Then *Br* and *Co* are combined in *DF*1 to give *B*.

To compute the components of true wind with respect to the line of sight, the compass direction (*Bw*) must first be converted to an angle which is relative to the line of sight. For this purpose the rangekeeper computes wind angle

(*Cws*) according to the following formula: $Cws = B - Bw + 180^\circ$.

As shown in figure 10–15 the subtraction of the hand input, *Bw*, from *B* takes place in the differential *DF*2. The 180° term is included in the equation because *Cws* is the angle between the direction TOWARD which the wind is blowing and the line of sight; whereas, *Bw*, the input is the compass direction FROM which the wind is blowing. This 180° is incorporated in the instrument at the time of adjustment as a constant offset.

Cws, the angle input to the wind component solver, is

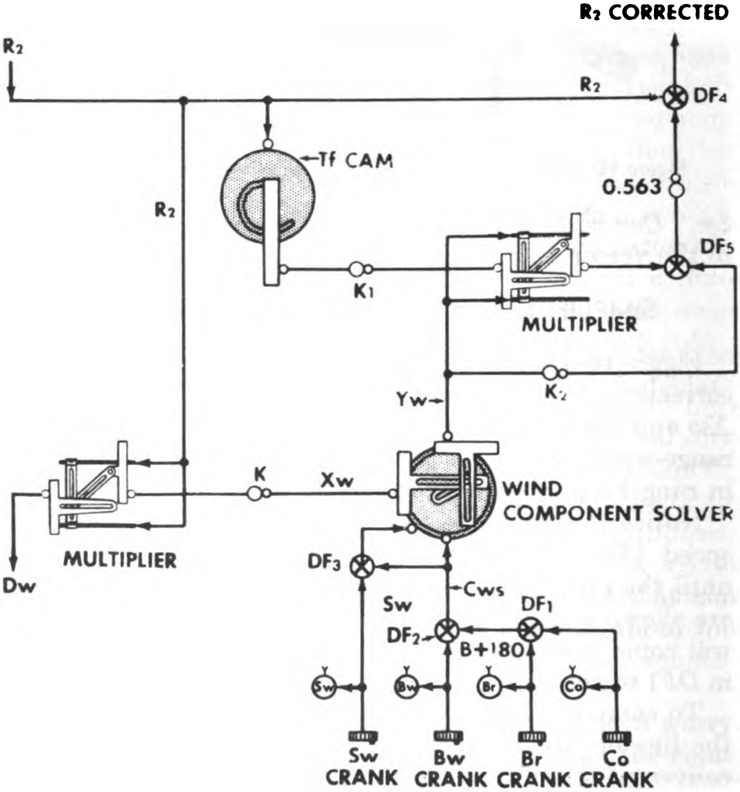


Figure 10–15.—Example of a device to compute wind corrections.

constantly changing as the target moves, but with this setup you need to introduce wind values only once. Then if the correct values of *Br* and *Co* are maintained, the correct value of *Cws* will always show up on the component solver input.

DF3 is the compensating differential which is found in every component solver. Compensating differentials are used to prevent the length of the vector from changing when the angle changes.

Deflection correction due to *Xw* is solved exactly the same as shown in figure 10–7, except that *Xw* is substituted for *Sw*. Range correction due to *Yw* is solved the same as in figure 10–8, except that *Sw* is again substituted for, but this time by *Yw*.

Review the computation step by step in figure 10–15 for range and cross wind. The range component (*Yw*) of the wind vector (*Sw*) is fed into the upper multiplier. The other input to the multiplier is *Tf*, which is obtained from a cam and multiplied by the constant *K*1 in a gear ratio before positioning the slide input.

Yw is multiplied in the gear ratio, *K*2, and the result is subtracted from the output of the multiplier in *DF*5. The result is the correction for advance range to compensate for range wind, and is combined with advance range at *DF*4.

Mils deflection due to wind is obtained by the approximate formula, $K \times Xw \times R2$. *R*2 and the *Xw* component of the wind vector are the inputs to a multiplier. The output is deflection due to wind or *Dw*.

This completes the study on wind corrections. It has told you about wind, but just as important, it has shown you how computing units like multipliers, differentials, and component solvers work together to compute the corrections necessary to take care of the ballistic error introduced into the fire-control problem by the unit.

QUIZ

1. When winds are weighted and plotted for different levels, the result is
   - a. average air density
   - b. ballistic wind
   - c. wind speed
   - d. wind direction
2. Which of the following winds is never considered when solving the fire-control problem?
   - a. Vertical wind
   - b. Ballistic wind
   - c. Range wind
   - d. Cross wind
3. The component of wind blowing across the line of sight causes changes to be made in
   - a. $E'g$
   - b. Bw
   - c. Ds
   - d. Vs
4. The formula $Sw \times Tf$ does not accurately express the deflection of a projectile by the wind because it does not
   - a. allow for range
   - b. allow for change of Sw at higher altitudes
   - c. weigh ballistic wind
   - d. allow for the deflection lag of the projectile behind Sw
5. The direction of range wind and LOF are
   - a. always at obtuse angles
   - b. always at acute angles
   - c. parallel to each other
   - d. perpendicular to each other
6. Range wind corrections are measured in
   - a. degrees
   - b. knots
   - c. mils
   - d. yards
7. Which of the following devices is NOT needed to solve the range wind correction $(K1 \times Sw \times Tf - K2 \times Sw)\ 0.563$?
   - a. A cam
   - b. A multiplier
   - c. An integrator
   - d. A differential

8. *Bw* is measured from true north
   a. clockwise to the direction toward which the wind is blowing
   b. counterclockwise to the direction from which the wind is blowing
   c. counterclockwise to the direction toward which the wind is blowing
   d. clockwise to the direction from which the wind is blowing
9. What value may substitute for LOF when measuring wind direction for surface fire?
   a. LOS
   b. *R2*
   c. *k*
   d. *Br*
10. *Cws* can be obtained from *B* and *Cw* by the use of
    a. cams
    b. multipliers
    c. integrators
    d. differentials
11. The cross wind component is equal to *Sw* multiplied by
    a. Sin *Sw*
    b. Cos *Sw*
    c. Sin *Cws*
    d. Cos *Cws*
12. The wind vector is resolved into range wind and cross wind by means of a
    a. gear ratio
    b. vector solver
    c. component solver
    d. multiplier
13. In order to convert linear deflection due to cross wind to mils, it is necessary to divide by
    a. 0.563
    b. 3.43
    c. advance range
    d. the reciprocal of *R2*
14. A cross wind deflects the projectile the most at the
    a. middle of the trajectory
    b. end of the trajectory
    c. beginning of the trajectory
    d. highest point of the trajectory
15. If 2,027 yards per hour is equal to 1 knot, the constant for converting knots to yards per second is
    a. 0.356
    b. 0.365
    c. 0.563
    d. 0.653

CHAPTER 11

RELATIVE MOTION PROBLEM

You have studied about the corrections for wind, gravity, and air resistance on a projectile during time of flight and how these corrections affect gun position. You also learned how to resolve and add vectors. In this chapter we will find out how own ship and target motion will affect gun position and how to calculate the necessary corrections.

Let us size up the problem for a moment by starting with the date received from the director. The director with its associated equipment transmits range and bearing of the target's PRESENT POSITION, the actual spot where the target is at any time. The rangekeeper takes this information, along with the estimated target course and speed, and predicts where the target will be after *Tf* has elapsed. That is, the rangekeeper must compute the FUTURE TARGET POSITION relative to own ship, and the line of fire (LOF). In surface rangekeepers the LOF is determined by computing the gun elevation and train orders (*E′g* and *B′gr*).

OWN SHIP MOTION

Think for a moment about the effect of own ship motion on the projectile. When the ship is stationary with no wind present, the projectile has only one velocity when fired, its initial velocity, I. V. When the ship is moving, the projectile has two velocities: the I. V. and own ship's speed, (*So*). Since ship's motion will be transferred to the projectile at the instant of firing, the point of aim of the gun must be changed from what it was for a stationary ship in order to hit the target. The changes will appear in sight angle, *Vs*, and in sight deflection, *Ds*.

For example, if own ship is moving toward the target the gun must be depressed in order to keep from over-shooting, that is, *Vs* must be DECREASED. If the ship is moving eastward relative to the target, the gun must be trained right to keep from landing the projectile left. *Ds* must contain a RIGHT correction.

Own ship motion is always represented by a vector whose magnitude is *So* (own ship speed), and whose direction is *Br* (relative target bearing) measured from the ship's centerline clockwise to the line of sight, LOS (shown in fig. 11–1). *So* is received from the pitometer log and *Br* is measured by the director. *Br* can be measured directly by the director only when the deck is level; a deck tilt correction must be added to director train to produce *Br* when the deck is tilted. Both *So* and *Br* are received by synchro transmission.

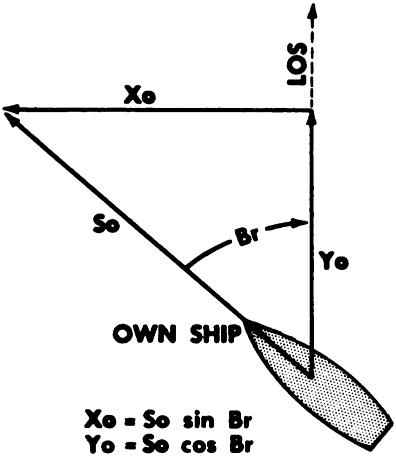


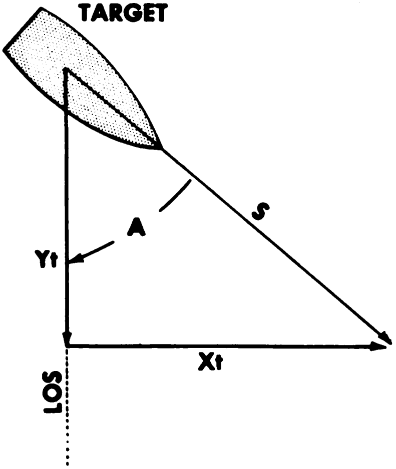
Figure 11–1.—Components of own ship motion.

Referring to figure 11–1 you will see that *So* has two effects: (1) that of shortening or lengthening range, and (2) that of deflecting the projectile left or right. To find the effect of own ship's movement on the range and on the deflection of the projectile, you have to break *So* into components in and across the *LOS* as you did with wind. These components are *Xo* and *Yo*. The DEFLECTION component *Xo* is calculated by multiplying *So* by sin *Br*, and the RANGE component *Yo* is found by multiplying *So* by cos *Br*.

These components are obtained mechanically from a component solver by setting *Br* in the angle gear and *So* in the vector gear.

TARGET MOTION

Target motion can be treated exactly the same way as own ship's motion. The target vector has a magnitude of target speed, (S) and a direction measured by the target angle, (A). Target angle is measured clockwise from the bow of the target to the LOS as indicated in figure 11–2.



Xt=S sin A

Yt=S cos A

Figure 11-2.—Components of target motion.

The target speed vector is broken down into components in and across the LOS the same as the own ship speed vector. These components are the target deflection component, (*Xt*), and the target range component, (*Yt*).

As shown in figure 11–2, *Yt* is obtained by multiplying *S* by cos *A*, and *Xt* by multiplying *S* by sin *A*. You can solve the range and deflection errors created by target motion by multiplying each by *Tf*.

The *X* components must be converted into MILS before they can become a correction to *Ds*.

Solving Own Ship and Target Motion

Lay out the own ship and target motion vectors on the same diagram showing all their references and angles as shown in figure 11–3. This figure shows the relationship of the own ship and target vectors, with all angles plotted with respect to true north.

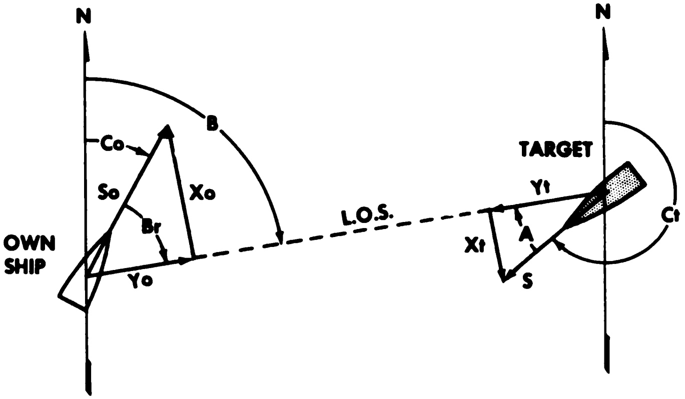


Figure 11–3.—Plot of own ship and target motion.

Target angle *A* can be estimated directly by the control officer in the director and transmitted to the plotting room via telephone. The estimated angle *A* is then cranked in at the rangekeeper by the operator as noted on the target dial group shown in the upper half of figure 11–4.

Target course (*Ct*) may be transmitted from CIC. Like *A*, it is cranked in while observing the target dial group. However, *Ct* is measured from north, and is read at the target ship's head on the CENTER RING DIAL (compass ring dial in figure 11–4). The target angle is read on the INNER DIAL (target dial) which is calibrated in degrees measured clockwise from the bow of the target ship to the LOS. Notice that the LOS is always fixed by an imaginary line formed by the lines engraved in the two indexes at the target and own ship dial groups. Regardless of whether you crank in *A* or *Ct* at the rangekeeper, you will always use the *Ct* handcrank.

At the OWN SHIP DIAL GROUP you can read own ship course (*Co*), true target bearing (*B*) and relative target bearing (*Br*). Own ship's course is read on the INNER DIAL with respect to the north mark on the compass ring dial. *B* is measured from north clockwise to the LOS, and is read on the RING DIAL at the index mark. *Br* is read on the INNER DIAL at the LOS index as measured from the bow of own ship.

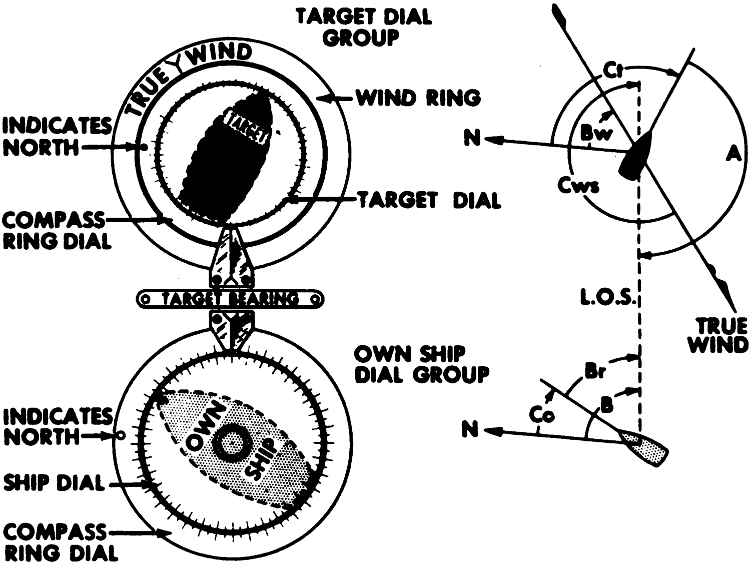


Figure 11–4.—Own ship and target dial groups.

You can get a firm picture of how these angles are set up on the dials by studying the plot of the angles on the right side of figure 11–4. Notice that own ship and target of the plot are lying in exactly the same position as in the dial group.

One other thing is illustrated in figure 11–4. Notice that Bw is cranked in by watching the angle the outer ring dial makes with north as read on the center ring dial.

Be sure you understand that when A is correct you also can read the correct value of Ct from the dials, or vice versa. This is because A is solved from B (which is equal to $Co+Br$) and Ct in the formula: $A=(B+180)-Ct$.

Look at figure 11–4 and notice that B is measured from north clockwise to the LOS at own ship. This is why you must add 180° to B to make the formula work out right.

To summarize the own ship and target motion calculations, study figure 11–5. Here the own ship and target vectors in and across the LOS are superimposed on the own ship and target component solvers.

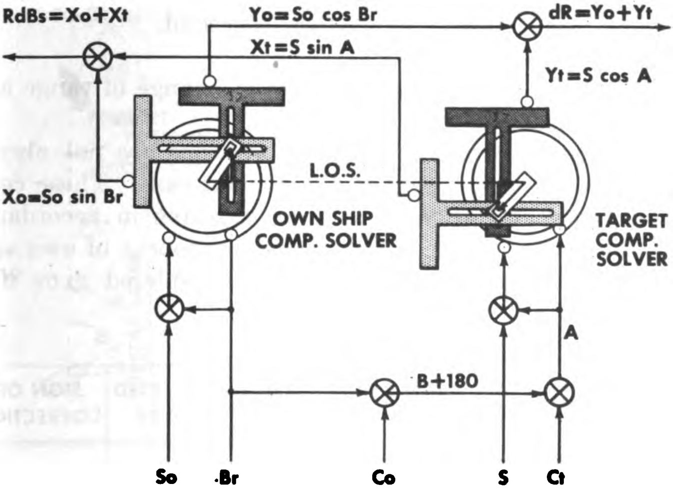


Figure 11–5.—Solving own ship and target motion components.

The angle gear of the target component solver is positioned by angle A which is made up from Br, Co, and Ct by the differential to give the vector input. The outputs at the component solver racks are Xt and Yt.

The own ship components are solved exactly the same way, except that *Br* and *So* position the inputs to the own ship component solver, and the outputs are *Xo* and *Yo*.

LINEAR RATES

The next step in solving the surface fire-control problem is adding up the components you have just computed. When *Yo* and *Yt* are added you get LINEAR RANGE RATE *dR*, the speed with which range is changing.

Likewise, when *Xo* and *Xt* are added you get the LINEAR DEFLECTION RATE *RdBs*, which is measured in yards at the target. After being converted to mils it tells the speed with which the deflection angle is changing.

Remember that the linear range rate and linear deflection rate are expressed by the following additions:

$$dR = Yo + Yt \text{ yards/second}$$

$$RdBs = Xo + Xt \text{ yards/second.}$$

These quantities represent the rate of change of range and linear deflection.

The plus signs in the above expressions are not always correct as they refer only to the general case. These components can be either positive or negative in accordance with the arbitrary rule that a range component of own ship or target motion (the correction) is considered PLUS if it

COMPONENT	ANGLE Br OR A	SIGN OF ERROR	SHOT FALLS ERROR	CORRECTED FOR BY	SIGN OF CORRECTION
Y RANGE	0-90 270-0	PLUS	OVER	DEPRESSING	MINUS
	90-180 180-270	MINUS	SHORT	ELEVATING	PLUS
X DEFLECTION	0-180	MINUS	LEFT	TRAIN RIGHT	PLUS
	180-360	PLUS	RIGHT	TRAIN LEFT	MINUS

Figure 11–6.—Summary of range and deflection components.

tends to INCREASE range, and MINUS if it tends to DECREASE range. Similarly, the deflection component of own ship or target motion (the correction) is considered PLUS if it tends to INCREASE the relative target bearing, or MINUS if it tends to DECREASE the relative target bearing. You can tie this rule together in the chart of figure 11–6.

RANGE PREDICTION

Since own ship and target are continually changing positions while the projectile is in the air, it is necessary to predict the future target position from changes in range rate, *dR*, and changes in linear deflection rate, *RdBs*. These computations are in addition to the regular trajectory corrections.

Figure 11–7 shows what happens to range during time *Tf*. The range changes, which means that you must determine exactly how much it will change and then add the total change to present range. This addition gives advance range, *R*2.

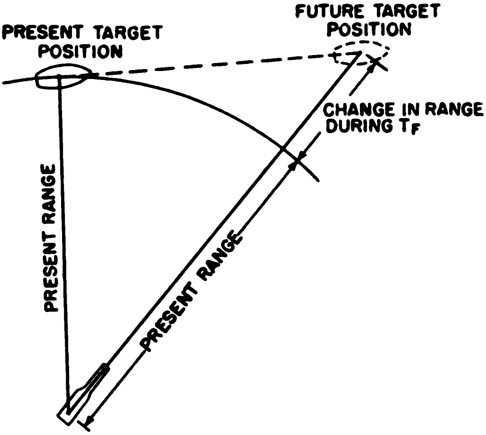


Figure 11–7.—Range prediction.

Once *R*2 is determined, it is easy to compute the sight angle, *Vs*. From the study of range tables you found that for every given range there is a corresponding value of *Vs*. Figure 11–8 shows the sight angle for a moving target. As you know, *Vs* will increase or decrease with range, but not directly. To compute *Vs*, a cam is cut to some function of *Vs* and positioned by *R*2.

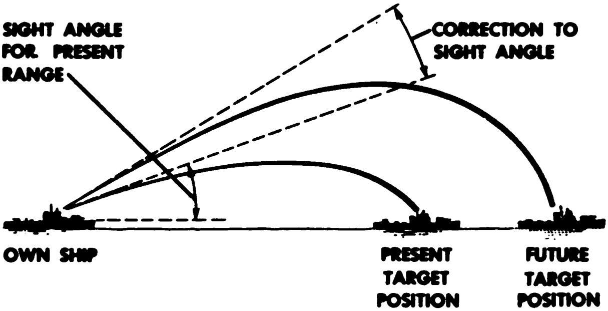


Figure 11–8.—Sight angle for a moving target.

This may seem like a round about way of getting *Vs*, but the big problem becomes the calculation of the total change in range, that is, to determine range prediction (*Rt*) due to both own ship and target motion. It can be computed in a number of ways, but regardless of how it is done, it will probably always seem a little difficult.

You know that *dR* tells the speed with which range is changing so at first thought it might seem logical to multiply *dR* by *Tf* to give the total change in range. If you did, your answer would be correct only for slow moving targets, since the value of *Tf* was taken only to present range—the only available value of range you have.

To be correct *Rt* must represent the amount the range changes (due to own ship and target motion) during the time (*Tf*) it takes the projectile to get to the final position of the target. With this in mind it should be obvious that you can not compute *Rt* from the *Tf* based on the range to present target position.

Instead, a *Tf* based on a certain range nearly equal to *R*2 should be used; however, for all practical purposes, a *Tf* based on *R*2 is used.

But how can you calculate *Tf* based on *R*2 when you need

Tf to calculate *Rt* to get *R*2? It sounds like a vicious circle, and, strange as it may seem, it actually is.

You can get the correct value of *Tf* by a regenerative process which is accomplished by feeding the output back into the input of a mechanical range prediction computer. This is really the same as putting in a series of substitutions which is carried on indefinitely in the machine until the answer, *Rt,* and in turn, *Tf,* is correct.

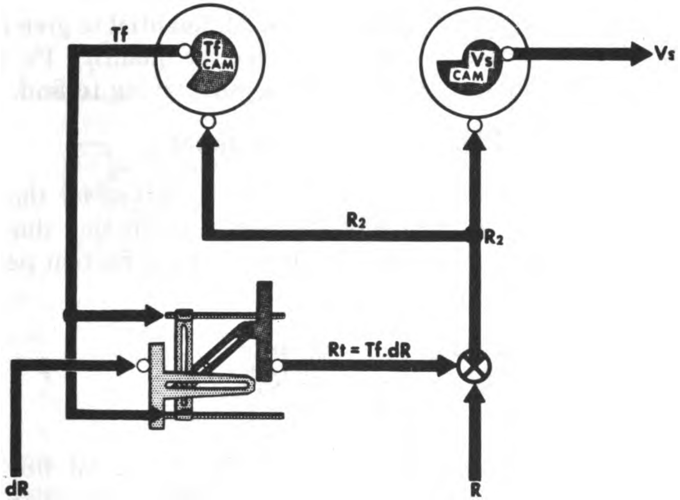


Figure 11–9.—Computing *Vs* with a simple ballistic computer.

An example will probably give you the idea better:

a. Find *Tf* to present range.

b. Multiply quantity (a) by *dR* to get the first approximation of *Rt.*

c. Add quantity (b) to present range to get the first approximation of *R*2.

d. Find *Tf* corresponding to the first approximation of *R*2, quantity (c).

e. Multiply quantity (d) by *dR* to get the second approximation of *Rt.*

f. Add quantity (e) to present range to get the second approximation of *R*2.

This could be continued indefinitely, although two substitutions would be accurate enough. Such a problem is worked by the machine shown in figure 11–9. The *Tf* cam and the multiplier solve the equation for range prediction due to own ship and target motion:

$$\text{range prediction} = (Yo + Yt)\ Tf$$

$$\text{or, } Rt = dR \times Tf.$$

Rt is added to present range *R* in the differential to give *R*2. Then *R*2 drives the *Vs* cam to produce the quantity *Vs*, the quantity you have spent such a long time trying to find.

DEFLECTION PREDICTION

In solving for range prediction, you also solved for the *Tf* and, since *Tf* is used to solve deflection prediction due to own ship and target motion, *Dt*, half of the deflection problem is already worked out.

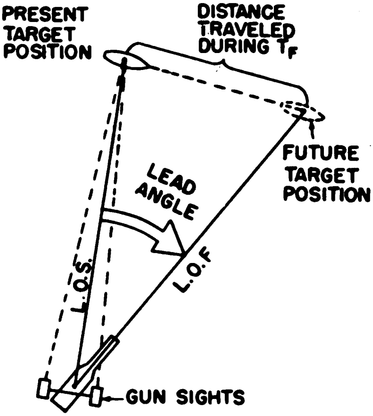


Figure 11–10.—Sight deflection for lead.

Before going into the details of solving deflection prediction let us first review the problem and see what deflection actually is. In the most simple case shown in figure 11–10, sight deflection *Ds* is the angle the gun must be offset from the LOS to allow for own ship and target motion during *Tf*. In short, you have to predict how much to LEAD the target so that the projectile and target will meet at a point at some future time.

You also have to correct *Ds* for things such as drift and wind. Therefore *Ds* includes all the corrections shown in figure 11–11. So where *Dt* is the deflection necessary to correct for own ship and target motion, *Df* is the correction for drift, and *Dw* is the correction for wind.

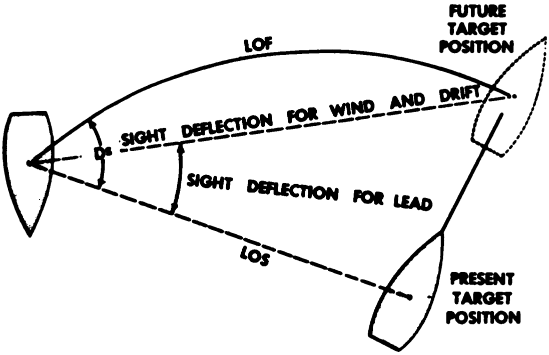

FUTURE TARGET POSITION
LOF
SIGHT DEFLECTION FOR WIND AND DRIFT
Ds
SIGHT DEFLECTION FOR LEAD
LOS
PRESENT TARGET POSITION

Figure 11–11.—Sight deflection *Ds*.

Now let us calculate *Dt*. The first step is to multiply *RdBs* (linear deflection rate in yards/second) by *Tf* as shown in figure 11–12, which gives linear deflection prediction at the target in yards. Then, to convert this value to mils, just divide by *R*2 in thousands of yards. Therefore, the formula is:

$$Dt = \frac{RdBs \times Tf}{R2} \text{ mils.}$$

In some cases it is necessary to have *Dt* in minutes rather than mils. This is a simple operation because all you have to do is multiply the result by 3.43, since 1 mil equals approximately 3.43 minutes. This can be handled by a gear ratio.

The simplest way of solving *Dt* in a rangekeeper is shown in figure 11–13A. This method involves only the use of a

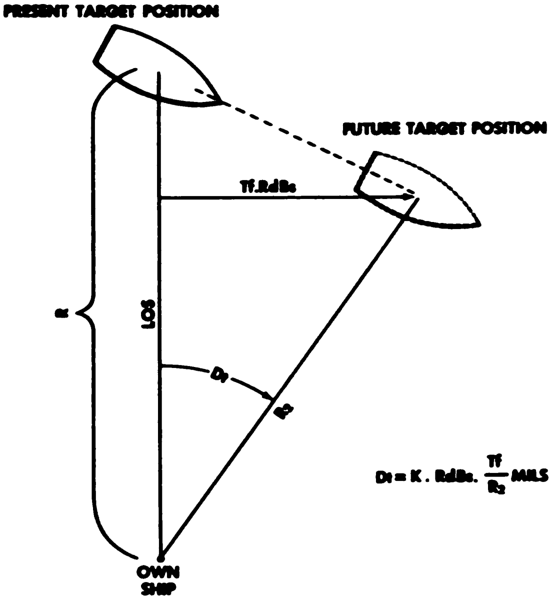


Figure 11–12.—Deflection prediction for own ship and target motion.

multiplier and a gear ratio to convert the product to minutes. However, a more accurate method, the one you will generally encounter, uses a differential in addition to the multiplier as in figure 11–13B. This latter method is more accurate because it utilizes the entire range of the multiplier.

Multipliers are built so that both inputs can go to zero. This is done so that, when doing a multiplication in which one of the terms never reaches zero, there will be an unused portion of the multiplier. For a given range of inputs the greater the amount of the multiplier which can be used, the greater the accuracy. For this reason attempts are often made to use full range of both slides from zero to maximum, and that is exactly what the arrangement in figure 11–13B is designed to do.

In figure 11–13B the expression $Tf/R2$ never reaches zero because the minimum range input never reaches zero. But by replacing the input $Tf/R2$ with an input $Tf/R2-K$, where

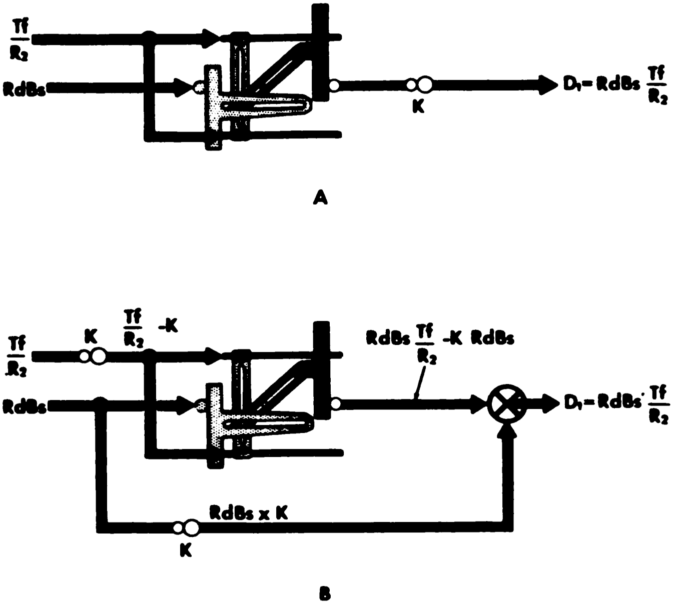


Figure 11–13.—Computing *Dt.*

K equals the minimum value of *Tf*/*R*2, the *Tf*/*R*2—*K* input will go to zero.

Refer to figure 11–13B again and see how the resulting unwanted *K* × *RdBs* in the product is removed in the differential. This is done by subtracting an equal quantity made from multiplying *RdBs* by *K* in a gear ratio. This actually increases utilization of the *Tf*/*R*2 slide of the multiplier by about 30 percent.

Range Effect of Deflection and I. V. Correction

The simple formula used to calculate *R*2 (and *Vs*) is not always accurate enough for mechanical rangekeepers and computers used in main battery and antiaircraft plotting rooms, because deflection prediction introduces a RANGE ERROR as shown in figure 11–14.

For small deflection angles this error is negligible, but with a fast moving target the deflection is increased and the error in $R2$ grows larger. A study of the diagram of figure 11–14 will reveal that where no deflection is present the error is zero.

The correction for range effect of deflection is called the range prediction due to deflection, and is represented by Rx. Rangekeepers make up Rx in a number of different ways and Rx will always be based on the fact that it is nearly proportional to $R2$ TIMES $(Dt)^2$, where Dt is mils deflection due to own ship and target motion.

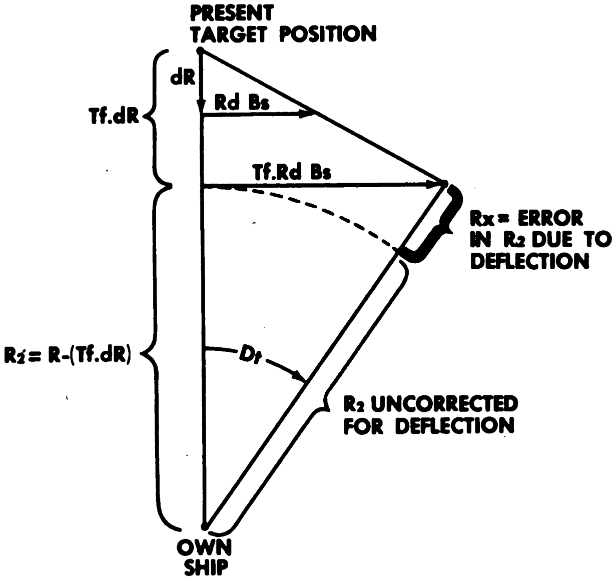


Figure 11–14.—Error in *R2* due to deflection.

Some rangekeepers go a little further by taking a new value (Dtw) based on the deflection prediction due to wind as well as for own ship and target motion ($Dtw = Dt + Dw$), exclusive of drift, and substitute this value for Dt. Then you can more accurately write: $Rx = R2 \times (Dtw)^2$.

But like most fire-control problems, this problem grows more complicated because, in actual practice, the rangekeeper also solves the range prediction to compensate for changes from initial velocity (*Rm*), in the same mechanism. Of course, this is more practical from the construction standpoint because it eliminates an extra multiplier which would otherwise be necessary if *Rx* and *Rm* were solved separately.

A computer that determines range prediction due to I. V. changes, deflection due to wind, and deflection due to own ship and target motion is shown in figure 11–15. It may appear to be a little complicated, but it is really quite simple.

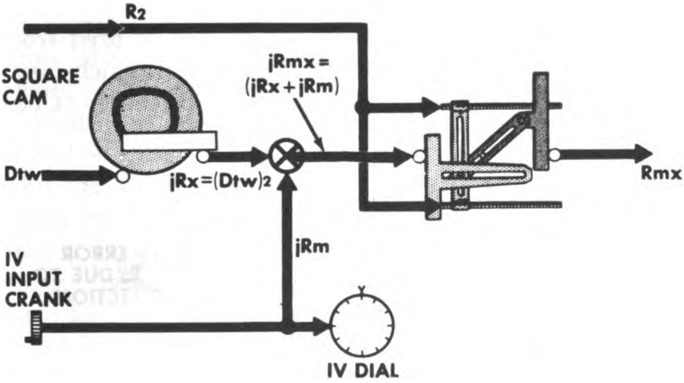


Figure 11–15.—Range prediction due to I. V. changes, wind and deflection.

Take one thing at a time starting with *Dtw*. First, *Dtw* is squared (according to the basic formula, $Rx = R2(Dtw)^2$) in a cam to give partial range prediction due to cross wind and own ship and target motion, *jRx*, which is equal to $(Dtw)^2$. Then *jRx* is added to partial range prediction due to I. V. change, *jRm*, and the sum ($jRmx = jRx + jRm$) is fed to the multiplier.

Note: The "j" preceding the symbols indicates partial correction.

Finally *jRmx* is multiplied by *R*2 in the multiplier to give *Rmx*. In practice, *R*2 plus some constant is used as the screw input to the multiplier, which is just another trick to get better results.

The I. V. dial in this computer is calibrated so that when you apply a correction in so many feet/second, the proper correction (*jRm*) is applied to the multiplier input, and when *jRm* (along with *jRx*) is multiplied by *R*2, the result produces the proper range correction due to I. V. change.

WIND CAUSED BY OWN SHIP MOTION

As a ship moves you can feel a breeze which has the same effect as a wind blowing directly astern. It is called HEAD WIND. The head wind speed is equal and opposite to own ship speed. If own ship is making 10 knots, then the head wind speed is 10 knots.

Consider for a moment a projectile that is fired from a moving ship. In addition to all other forces which may be acting upon it, head wind will resist the projectile. Corrections for this head wind must be made to get hits.

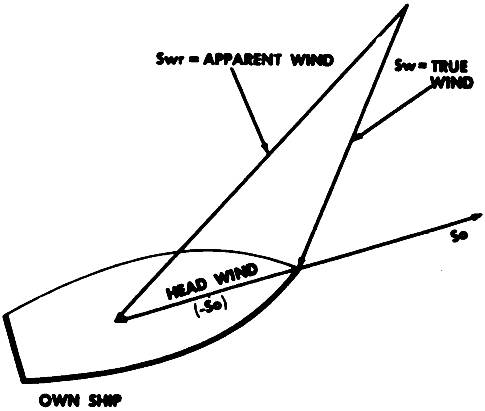


Figure 11–16.—Apparent wind.

Now consider what happens when the ship is moving along with an actual wind present, and this wind makes an angle with the ship's course as shown in figure 11–16. Two wind forces are now acting on the projectile. But here again you can think of these two winds as one resultant wind called APPARENT WIND, *Swr*. Figure 11–16 shows how true wind and head wind are combined to give *Swr*.

In computing the effect of apparent wind on the trajectory of the projectile, you could proceed as usual except that you would use the apparent wind speed *Swr* instead of true wind *Sw*, and you would use apparent wind direction *Bwr* instead of true wind direction *Bw*.

There is a decided disadvantage in using apparent wind angle and speed as rangekeepers inputs, because every time own ship changes course and speed, the value and direction of the velocity vector of apparent wind also changes. You can see this is true in figure 11–16; assume that own ship changes course with respect to true wind and figure it out for yourself. Most rangekeepers take *Sw* and *Bw* as inputs because they never have to be changed unless true wind changes. The *Sw* vector is then resolved into *Xw* and *Yw* components IN and ACROSS the LOS and added to the own ship components.

This may look like a roundabout way of calculating corrections for apparent wind, but the nice thing about it is that this method automatically takes care of apparent wind changes due to changes in own ship course and speed. Thus, when you add the true wind and own ship components, you get the apparent wind components IN and ACROSS the line of sight. Mathematically you can write:

$Xwr = Xw + Xo$ = component of apparent wind velocity ACROSS LOS.

$Ywr = Yw + Yo$ = component of apparent wind velocity IN LOS.

As you learned in the wind chapter, *Xwr* corrects sight deflection *Ds* and *Ywr* corrects sight angle *Vs* by correcting advance range *R*2. At this point you should get an idea of how these wind quantities are treated in an actual machine. Let us start by studying how *Dw* is made up from *Xwr*, as shown in figure 11–17.

Refer to figure 10–7 and you will see that *Dw* is made from $R2 \times K\ Sw$ (where *Sw* was assumed to be cross wind velocity). You can solve for apparent wind in the same formula by substituting *Xwr* for *Sw*. *K* varies to compensate for the slowing down of the projectile at the end of its trajectory. Thus, *K* varies in the same way as the *Tf* or *Vs* functions of

$R2$; it increases faster than range. Consequently, instead of being computed from a cam, the value of K is computed from other quantities (usually Vs) already present in the machine.

Some machines compute Dw by multiplying Xwr by $R2 \times K$, as in the wind problem, but other machines, like the one shown in figure 11–17, make up a more accurate value of Dw by multiplying Xwr by $Vs+K1$. It should be apparent that $Vs+K1$ increases faster at longer ranges because that is the way Vs varies. If you cannot remember how the wind correction varies with range, go back to the wind chapter and review the cross wind section.

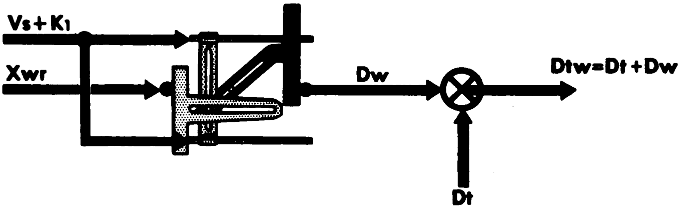


Figure 11–17.—Computing deflection prediction due to wind and own ship target motion.

Dw is then added to Dt in a differential to make up deflection prediction due to wind and own ship and target motion, Dtw, as shown in figure 11–17.

Next, see how Ywr is treated. Range prediction due to wind (Rw) is solved in the SAME MULTIPLIER that computes Rt. This multiplier is called the RANGE PREDICTOR. Its output is range prediction due to own ship and target motion and wind, Rtw, which is equal to Rt plus Rw; however, neither Rt or Rw appear SEPARATELY in a rangekeeper because the multiplier computes them simultaneously. You will recall from figure 10–9 that:

$$Rt = Tf \times dR$$

Now, since Rtw is equal to Rt plus Rw, you can write

$$Rtw = Rt + Rw$$

or, by substituting the above values for Rt and Rw, you get

$$Rtw = Tf \times dR + (Tf \times K \times Ywr - K1 \times Ywr).$$

Also, by removing the parentheses and rearranging:

$$Rtw = Tf \times dR - Tf \times K \times Ywr + K1 \times Ywr$$

$$Rtw = Tf\ (dR - K \times Ywr) + K1 \times Ywr$$

This is the formula the multipliėr solves with the assistance of two differentials, and two gear ratios to take care of the constants. In order to keep from repeating the long term Tf $(dR - K \times Ywr)$ over and over again on drawings, and prints, it has been given the symbol $jRtw$, which is called partial range prediction for wind and own ship and target motion. Then you have: $Rtw = jRtw + K1 \times Ywr$.

Figure 11–18 shows how this last formula is solved. To see how it works, first assume that Ywr is zero (no wind correction present), as shown in figure 11–18A. With Ywr at zero the multiplier simply multiplies Tf by dR to give range prediction due to own ship and target motion Rt, which in this case is equal to Rtw.

But with apparent wind present as shown in figure 11–18B, the side gears of $DF1$ and $DF2$ are offset by Ywr (which is modified by two constants). Then $K \times Ywr$ is subtracted from dR in $DF2$ to produce $dR - K \times Ywr$, which is multiplied in the multiplier by Tf to give $jRtw$. Finally, $K1 \times Ywr$ is added to $jRtw$ in $DF1$ to give Rtw.

COMPUTING SIGHT ANGLE AND SIGHT DEFLECTION

You are now ready to complete solving the problem of own ship and target motion, wind, I. V. correction, range and deflection prediction, and make up sight angle (Vs) and sight deflection (Ds) including all their corrections. The best way to learn about Ds and Vs is to put all the foregoing diagrams together and study them as a whole. Let us take Ds first.

The Ds computer in figure 11–19 is really just a review of figures 11–13 and 11–17. As you learned earlier, Ds is equal

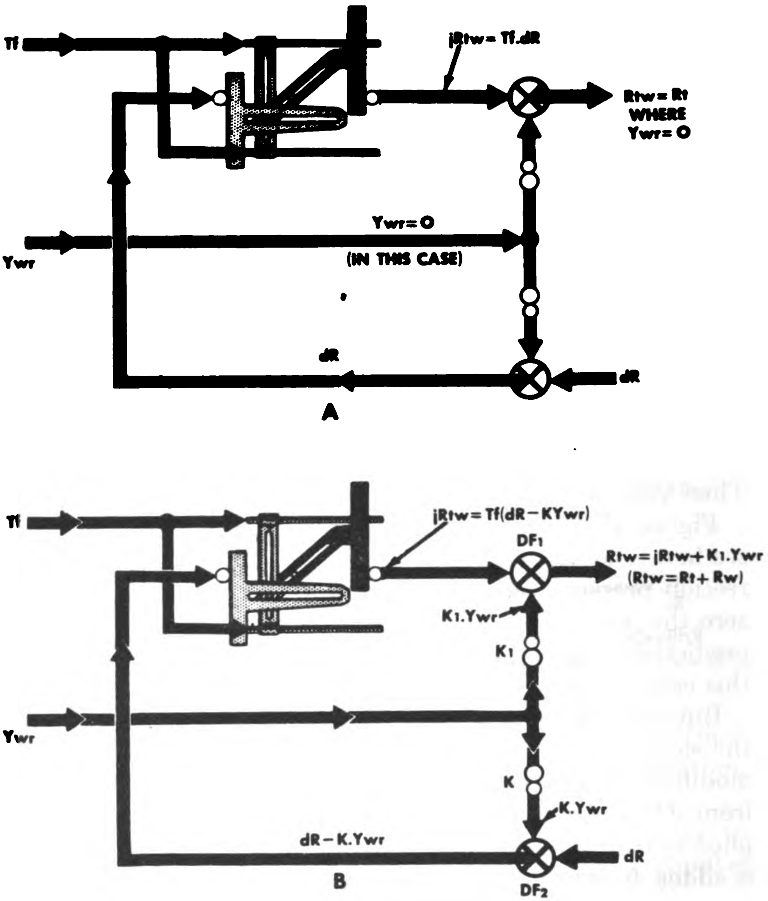


Figure 11–18.—Solving range prediction due to wind and own ship and target motion.

to the SUM of *Dt*, *Dw* and *Df*. Each of these three quantities is computed separately. *Dt* is computed in the TARGET DEFLECTION PREDICTOR multiplier, and *Dw* is solved in the WIND DEFLECTION multiplier. But *Df* is made up a little different than anything you have computed so far.

If you stop to think back it should be apparent that both *Vs* and *Df* increase with range, but they increase faster and faster as range increases. Thus, you can say that both *Vs* and *Df* vary as functions of *R*2. Since both are functions of advance range, it follows that *Df* is equal to some function of *Vs* which can be expressed mathematically as *Df*=*f* (*Vs*), as shown in figure 11–19.

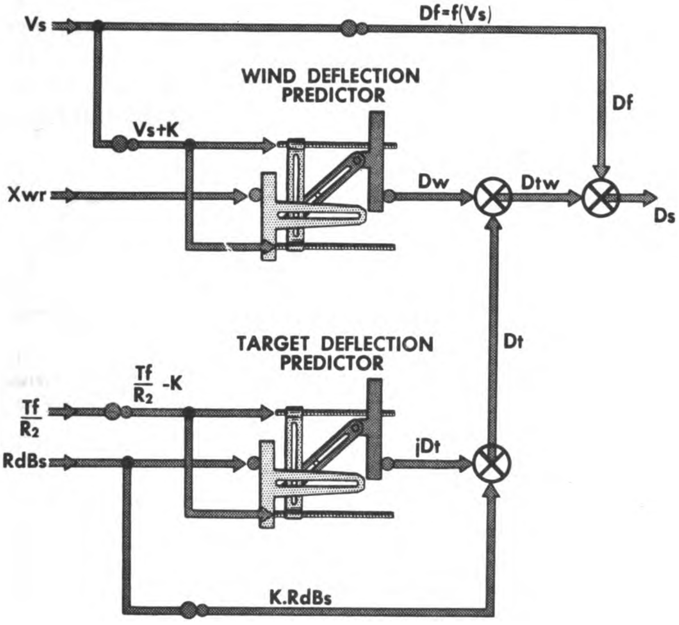


Figure 11–19.—Solving for sight deflection *Ds*.

This formula has a very general meaning; however, it shows that there is a relationship between *Df* and *Vs*, and that is all you need to know here. Proper shafting and gearing to take care of the constants do the rest. These constants are built into the computer so you will not have to worry about them.

Total range prediction is solved with a couple of cams and multipliers, several differentials, and a few gear ratios to take care of the constants. Refer to figure 11–20, which includes all the component sections you have studied in figures 11–9, 11–15, and 11–18, to get the picture of how these sections go together to solve for *Vs*.

The accuracy of the solution of Vs depends on how accurately $R2$ is computed. If $R2$ is correct, then Vs is correct, since Vs is taken from a cam positioned by $R2$. When all its corrections are in, $R2$ is corrected for wind, own ship and target motion, error due to deflection, and I. V. Thus you can say mathematically that

$$R2=Rt+Rw+Rm+Rx+R.$$

However, only R exists separately in actual computers because each multiplier computes two things simultaneously.

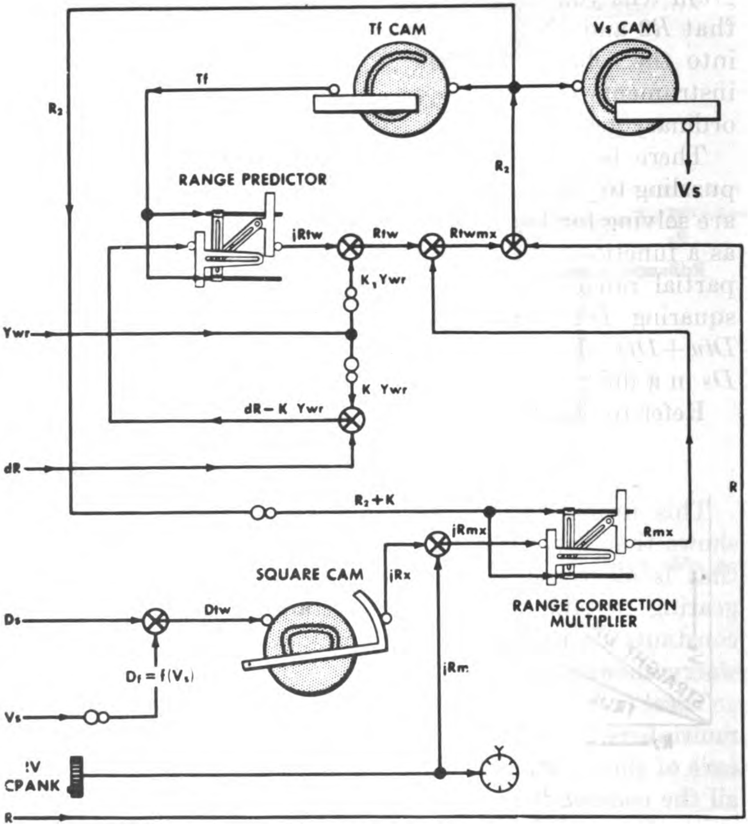


Figure 11–20.—Solving for sight angle *Vs.*

For example, the range predictor multiplier in figure 11–20 solves *Rw* and *Rt* together, with the inputs *dR*, *Ywr*, and *Tf*, to produce *Rtw*. And the range correction multiplier computes *Rx* and *Rm* together, with the inputs *Ds*, *I. V.*, and *R*2, to give *Rmx*. Then *Rtw* and *Rmx* are added in a differential to give TOTAL range prediction, *Rtwmx*. Finally, the total range prediction, *Rtwmx* is added to present range *R* in another differential to give advance range *R*2.

It is easy to see that the entire *R*2 computer is a regenerative affair as several functions of *R*2 are fed back to the inputs to make up corrections in *R*2. A study of the diagram tells you that *Tf*, made from *R*2, helps make up *Rtw;* that *R*2 and *Vs* (also made from *R*2) are fed back to enter into the solution of *Rmx*. As you work with fire-control instruments you will learn to accept regenerative devices as ordinary gear.

There is one other thing in figure 11–20 that may be puzzling to you: to have both *Ds* and *Vs* as inputs when you are solving for *Vs*. This is necessary because *Df* is made up as a function of *Vs*, and, as you learned in figure 11–15, the partial range correction for deflection, *jRx*, was made by squaring *Dtw*. Since *Ds* contains *Dtw* (remember *Ds*=*Dtw*+*Df*), all you have to do to get *Dtw* is subtract *Df* from *Ds* in a differential, as is indicated in figure 11–20.

Refer to figure 11–20 again and locate the *Vs* cam. *Vs* is

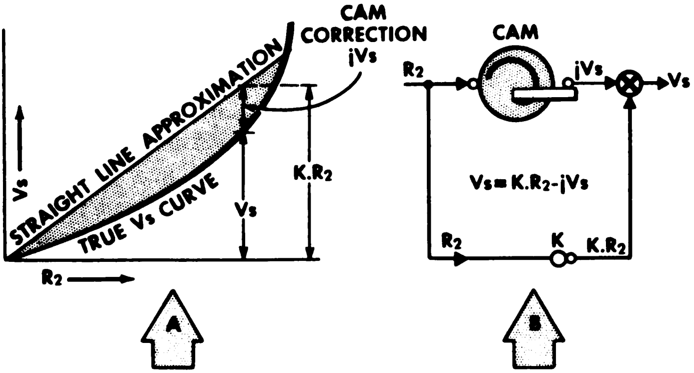


Figure 11–21.—Computing *Vs* from a straight line approximation.

not computed directly from a cam as indicated; actually, only a partial value of *Vs* called *jVs*, is computed. This partial value of *Vs* is then added to the product of *R*2 times a constant to give *Vs*.

The true *Vs* curve is shown in figure 11–21A; it is the heavy lined curve, and is plotted against values of *R*2.

Now if all values of *Vs* were to be computed in a cam, the cam would have to be extremely large to be accurate. So in order to use a smaller cam, a STRAIGHT LINE APPROXIMATION of *Vs* is computed by multiplying *R*2 by a constant in a gear ratio as shown in figure 11–21B. When plotted, $K \times R2$ produces the straight line approximation indicated in figure 11–21A. The cam then solves the distance between the two curves (the shaded area) corresponding to various *R*2 values, which is the difference (*jVs*) between the straight line and the true *Vs* curve. This difference value of *jVs* is subtracted from the straight line approximation, $K \times R2$, in the differential to give *Vs* as shown in figure 11–21B.

Vs is not the only function of *R*2 that is computed by the use of a straight line approximation; among others, *Tf* is computed in exactly the same way.

That completes the study of *Vs* and *Ds*. You are not expected to memorize how *Vs* and *Ds* are computed, but you should be able to trace a blueprint of a surface rangekeeper to see how these two quantities are made up without any trouble. Refer to figure 11–22 and trace out the entire print.

The best way to trace out any schematic diagram is to start with the inputs and then work on through the print to the outputs taking one quantity at a time. The inputs in figure 11–22 are shown in circles. You will notice that most of the constants that were mentioned have been left out.

Constants that are not important to adjustment information are purposely left out in actual prints, so right now is a good time to get accustomed to working without them. However, if you need more detailed information about figure 11–22, refer to the previous figures of each section and study them more carefully.

In all rangekeeper computations thus far it has been

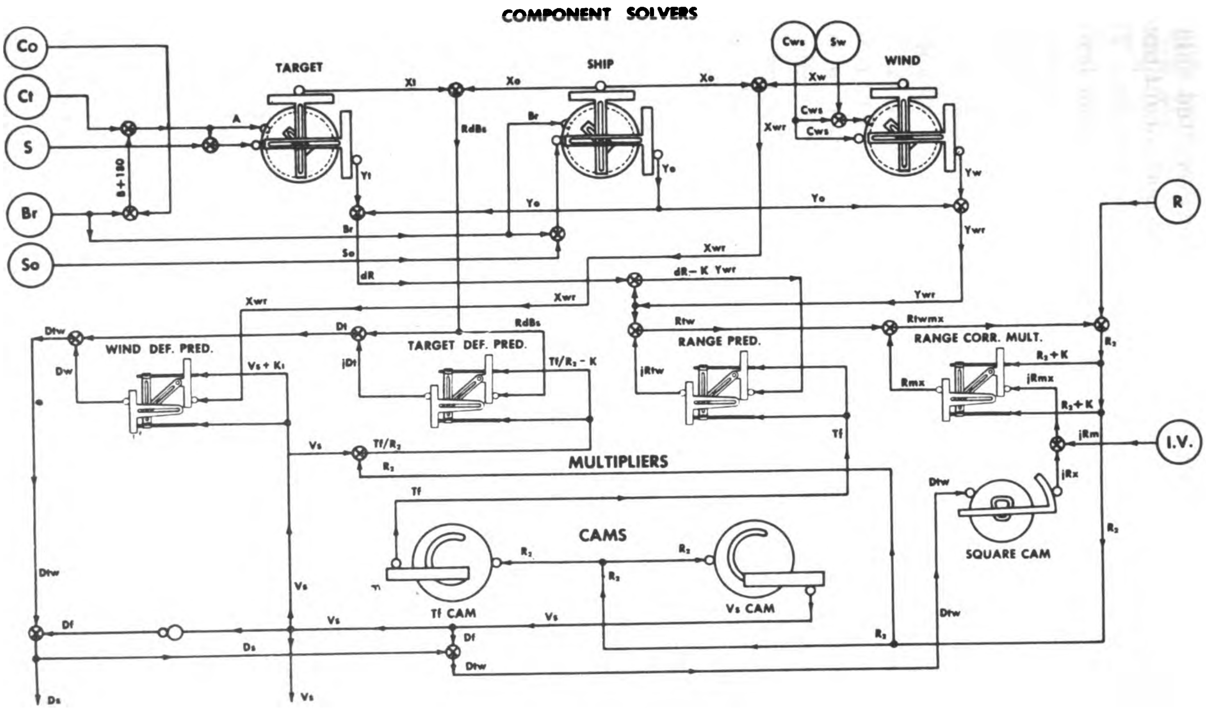


Figure 11–22.—Simplified ballistic computer similar to those used in surface rangekeepers.

assumed that basic quantities, such as *Br*, are always measured in the true horizontal plane. However, the ship is always rolling and pitching, which means that a continuous correction must be added to director train to give *Br*. This will be discussed in a following chapter.

QUIZ

1. *Ct* is measured from true north to
   a. the target bow
   b. the LOS
   c. own ship's bow
   d. the target bearing from own ship's bow
2. What are the inputs to own ship's component solver?
   a. *Br* and *So*
   b. *S* and *So*
   c. *Co* and *So*
   d. *Co* and *Br*
3. The linear deflection rate is determined from
   a. *Yo* and *Yt*
   b. *Xt* and *Yt*
   c. *Xo* and *Yo*
   d. *Xo* and *Xt*
4. *Tf* must be determined according to
   a. *R*
   b. *Rt*
   c. *dR*
   d. *R2*
5. *Tf* for the deflection prediction is obtained from the
   a. range prediction *Tf* cam
   b. *Vs* cam
   c. *Rt* multiplier
   d. *RdBs* multiplier
6. For the formula, $\frac{RdBs \times Tf}{R2}$, *R2* must be expressed in
   a. degrees
   b. mils
   c. yards
   d. thousands of yards

7. Which of the following devices is NOT used to compute *Dt*?
   a. Integrator
   b. Multiplier
   c. Differential
   d. Gear ratio
8. The introduction of *K* into the *Dt* computer multiplier permits an increase in the utilization of the multiplier of about
   a. 5%
   b. 10%
   c. 20%
   d. 30%
9. For computer purposes head wind is always equal to own ship's
   a. speed
   b. speed minus true wind
   c. speed plus true wind
   d. speed plus apparent wind
10. Which of the following values are added to obtain apparent wind along the LOS?
    a. *Xo* plus *Xw*
    b. *Yo* plus *Yw*
    c. *Xo* plus *Yo*
    d. *Yw* plus *Xw*
11. If *Ywr* and *dR* were zero, the input to the range predictor would be equal to
    a. *K*
    b. *R2*
    c. *Tf*
    d. *Rd*
12. *Df* varies as a function of
    a. *Vs*
    b. *Sw*
    c. *dR*
    d. *Co*
13. In actual computers, as contrasted with mathematical theory, which of the following values exists as a separate quantity?
    a. *R*
    b. *Rm*
    c. *Rx*
    d. *Rt*
14. Which of the following quantities is both computed by, and fed back to, the *Vs* computer?
    a. *R2*
    b. *R*
    c. *Ywr*
    d. I. V.

15. $K \times R2$, the approximation to Vs, is computed from $R2$ by
    a. a cam
    b. a gear ratio
    c. an integrator
    d. a sector multiplier
16. Which of the following values is computed like Vs from a linear approximation?
    a. A
    b. $R2$
    c. Tf
    d. Vz
17. How does the jVs cam output act on the Vs approximation, $R2 \times K$?
    a. It reduces it to Vs
    b. It increases it to Vs
    c. It subtracts the constant K
    d. It adds the constant K
18. Ds is equal to the sum of
    a. Dt and Dw
    b. $Dtwj$ and Dw
    c. Dt, Dw, and Df
    d. $RdBs$, Dt, and Df
19. When total range prediction ($Rtwmx$) is added to present range, you get
    a. Vs
    b. dR
    c. $RdBs$
    d. $R2$

CHAPTER 12

DECK AND TRUNNION TILT

Guns are installed with their roller paths parallel to the deck plane so that their movement is limited to train in the deck plane and elevation above the deck plane. Since the deck plane of a moving ship deviates from the horizontal by the amount of roll and pitch, some means must be found to measure and correct for this discrepancy. Correction for deck inclination is most satisfactorily applied in the solution of the fire control problem if it is resolved into components in planes IN and ACROSS the line of sight. The component in the line of sight, called level, then becomes a correction to elevation; while the component across the line of sight, called cross level, affects both train and elevation as it causes the trunnions of the guns to tilt.

The primary method of measuring level and cross level is

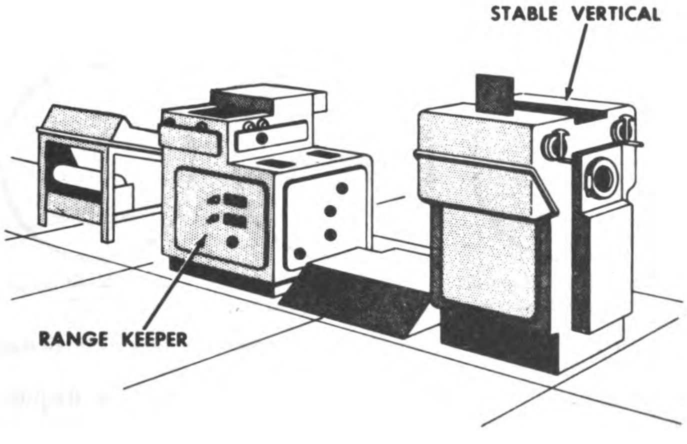


Figure 12–1.—Layout of a main battery plotting room.

with a stable element or a stable vertical, which is essentially a gyroscope equipped with suitable mechanical and electrical pick-offs. A sketch of a typical main battery setup employing a stable vertical is shown in figure 12–1. Although the measurements performed by the stable element and stable vertical are quite similar, only those pertaining to the stable vertical will be discussed in this chapter.

The stable vertical has two important jobs: to supply corrections for DECK TILT and TRUNNION TILT.

The purpose of deck tilt correction is to establish a true horizontal plane in the rangekeeper for the computation of all ballistic corrections. The purpose of trunnion tilt correction to modify the gun train and elevation orders, which are made up by the rangekeeper, to compensate for the tilt of the gun trunnions.

LEVEL AND CROSS LEVEL

If you were a director pointer or a director trainer sighting on a target through a telescope with no optical corrections present, the target would appear to move with respect to the telescope crosswire as indicated in figure 12–2. If the ship were tilted in a vertical plane containing the LOS, the target would appear to be under or over the horizontal crosswire as indicated in the left view of the target in figure 12–2.

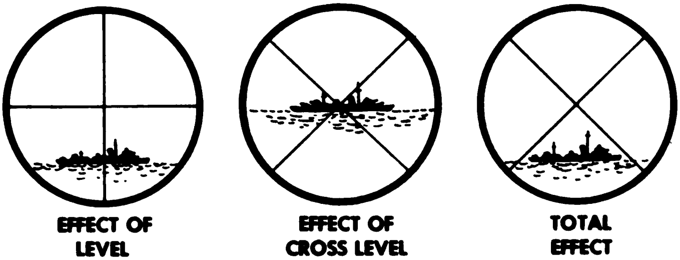


Figure 12–2.—What the pointer and trainer observe through their telescopes.

The angle by which the crosswire intersection is displaced VERTICALLY from the target is called the LEVEL ANGLE.

Looking at it another way, if the ship tilts around the LOS as shown in the center view of figure 12–2, the crosswires will remain on the target, but they will appear to rotate one way or the other. The angle, measured in a VERTICAL plane across the LOS, made by the horizontal crosswire and the true horizontal, is called CROSS LEVEL.

With both level and cross level present, you would see the target through the crosswires as shown in the right view of figure 12–2. Notice that the telescope crosswires are displaced vertically as a result of level, and rotated around the LOS as a result of cross level.

Like all other computations we have made so far, the LOS is the reference line for measuring level and cross level. Figure 12–3 shows that the level angle is measured in a VERTICAL PLANE CONTAINING THE LOS and cross-level angle is measured in a VERTICAL PLANE AT RIGHT ANGLES TO THE LOS.

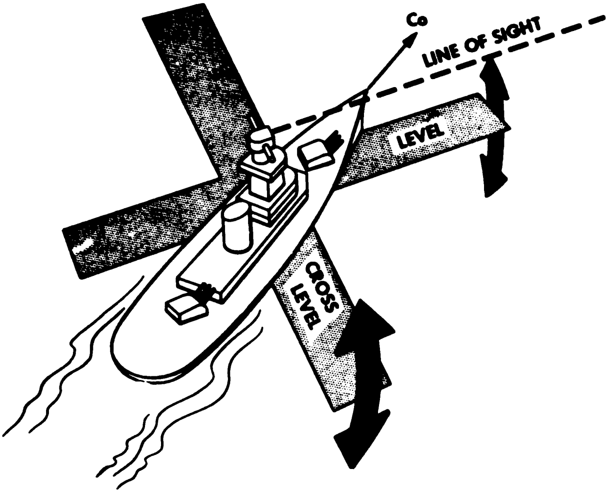
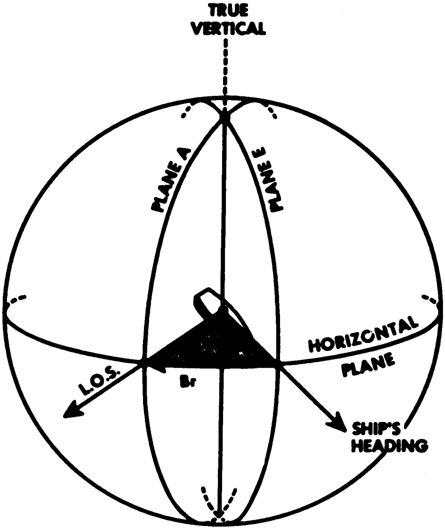


Figure 12–3.—The level and cross-level angles are measured in respect to the LOS in vertical planes indicated by the arrows.

To describe fully the level and cross-level angles as measured by the stable vertical, it is necessary to look into spherical diagrams, like the one in figure 12–4, and study the angles between certain planes INSIDE the sphere for different tilts

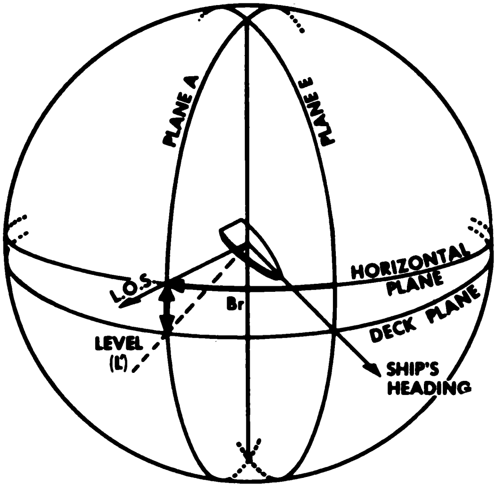


PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 12–4.—When the deck is level (coincides with the horizontal plane as shown), no level or cross level is present.

of the ship's deck. The drawing in figure 12–4 is a basic spherical diagram which illustrates the situation when the deck coincides with the horizontal plane. Notice that the director LOS is positioned through the angle *Br* (relative target bearing) from plane *E* to plane *A*. When the ship's deck is level, neither level nor cross level is present.

If the ship's deck is tilted, as shown in figure 12–5, so that all the tilt is in the plane containing the LOS, only level, *L′*, is present. You can see that *L′* would displace the LOS to a point below the horizontal as shown by the dotted line in figure 12–5. A tilt of the ship's deck in the opposite direction would move the LOS above the horizontal. Look at it this way: The gun must be elevated to compensate for level when the deck is tilted as shown in figure 12–5, but if the deck is tilted in the opposite direction, the gun must be depressed to correct for level.



PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 12–5.—When the deck is tilted as shown, only level is present.

Now imagine that the deck of the ship is tilted across the LOS, as shown in figure 12–6. The angle that plane *D* makes with plane *A* is cross level, *Zh*. Notice that *Zh* has no tendency to displace the LOS in the absence of *L′*.

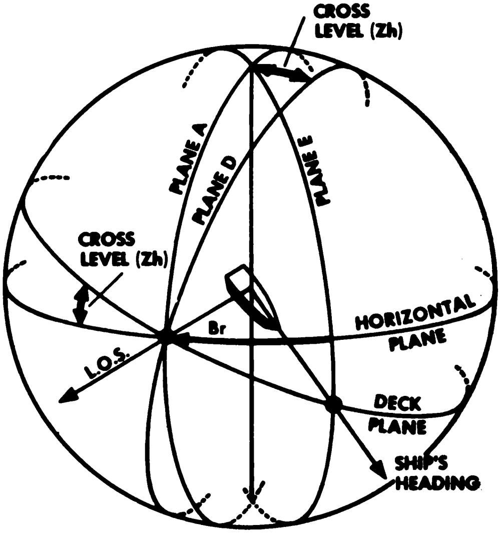
Figure 12–7 shows what happens when both level and cross level are present. A study of the diagram shows that if no corrections were made, the *LOS* would be displaced below the horizontal plane as indicated by the dotted line.

Summing it up, level and cross level are ERRORS caused by the roll and pitch of the ship and they must be corrected to get hits. Briefly, the stable vertical measures these errors and transmits their corresponding corrections, *L′* and *Zh*, to the rangekeeper to enter into the computation of the gun orders. Before leaving this section, be sure you understand that *L′* is measured in a VERTICAL PLANE containing the LOS, and *Zh* is measured as tilt ACROSS the LOS: Otherwise, a thorough understanding of what the stable vertical does will be difficult.

The stable vertical consists primarily of a high-speed gyro which spins in the vertical plane. It is kept in the vertical plane by the latitude correction and gimbal rotation righting forces. Thus, the gyro spins in the true vertical at all times and the ship appears to tilt about the gyro. This provides an excellent means of measuring level, *L′*, and cross level, *Zh*.

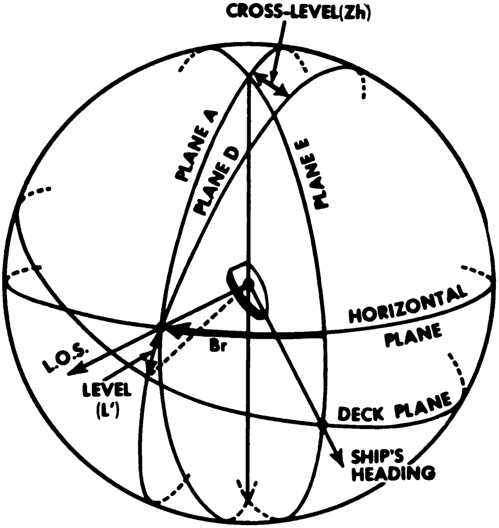
To see how the stable vertical does its job, refer to figure 12–8. If the gyro is always oriented so that one gimbal axis remains in the LOS and the other across the LOS, as indicated, the tilt of the gyro in the vertical plane containing the LOS will measure level, whereas the gyro tilt across the LOS will measure cross level.

The stable vertical does all this with only one input, director train *B′r′*, or relative target bearing as measured by the train of the director in the deck plane of the ship. Thus,



PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE D PLANE PERPENDICULAR TO DECK PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 12–6.—When the deck is tilted around (across) the LOS, without displacing it vertically, only cross level is present.



PLANE A	**VERTICAL PLANE CONTAINING L.O.S.**
PLANE D	**PLANE PERPENDICULAR TO DECK PLANE CONTAINING L.O.S.**
PLANE E	**VERTICAL PLANE THROUGH CENTERLINE OF SHIP**

Figure 12–7.—When the deck is tilted across and in the LOS as shown here, both level and cross level are present.

as the director is trained from the ship's centerline around to the LOS, it trains through the angle *B′r′*. Therefore, director train establishes the LOS. In short, to position the gyro gimbals relative to the LOS as shown in figure 12–8, *B′r′* is transmitted to the stable vertical from the director.

Figure 12–9 shows a simplified stable vertical placed outside of its case and mounted on a ship. The figure also shows the names of the various major parts. *B′r′* is received electrically from the director by synchro transmission and a servo follow-up motor. The servo (not shown) drives the training shaft.

Above the gyro assembly there is mounted a magnet which is energized with 115 volts a. c. from the fire-control switchboard. An umbrella, (a set of electrical figure-eight coils—

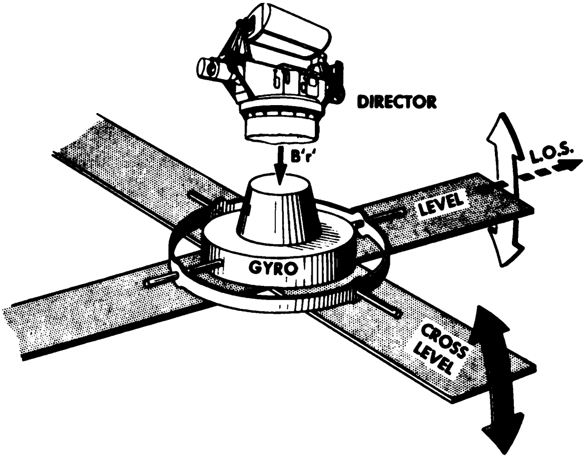


Figure 12-8.—The gyro measures level and cross level.

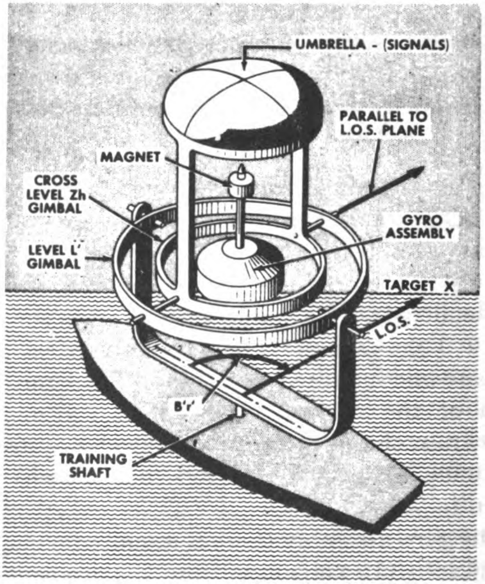


Figure 12-9.—Simplified stable vertical schematic diagram.

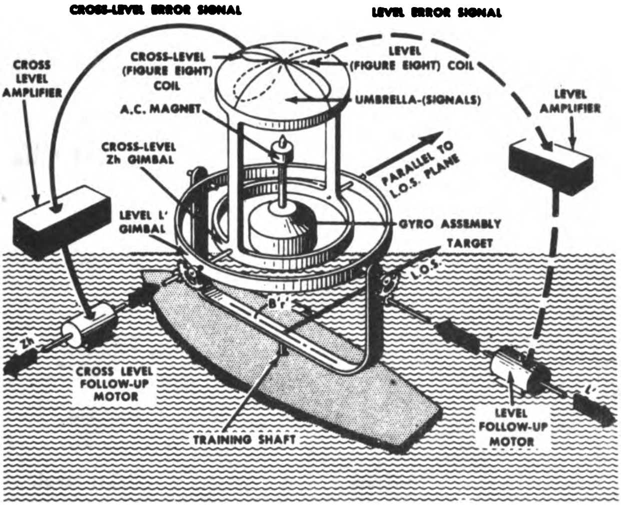


Figure 12–10.—Stable vertical follow-up control assembly.

one for level and one for cross level) is mounted on the cross level gimbal as shown in figure 12–10.

When the umbrella is over the magnet, the net voltage in its coils becomes zero and the follow-up motors stop. Therefore, in re-positioning the umbrella, the level and cross level follow-up motors have driven out the *L′* and *Zh* angles at their shafts.

How the Stable Vertical Measures Level

In figure 12–11 the deck has tilted so that all of the motion is about the level axis; that is, motion is about the pivots of the outer or level gimbal on the supporting fork. This displacement about the level axis is the LEVEL ERROR.

When the deck is inclined as shown in figure 12–11, the outer, level gimbal initially partakes of deck motion, and the umbrella moves with respect to the a-c magnet, which is maintained in the vertical by the gyro. An electrical signal is now generated in the level figure-eight coil. This signal is amplified by the level amplifier (see fig. 12–10) whose output excites the level follow-up motor. As the motor drives,

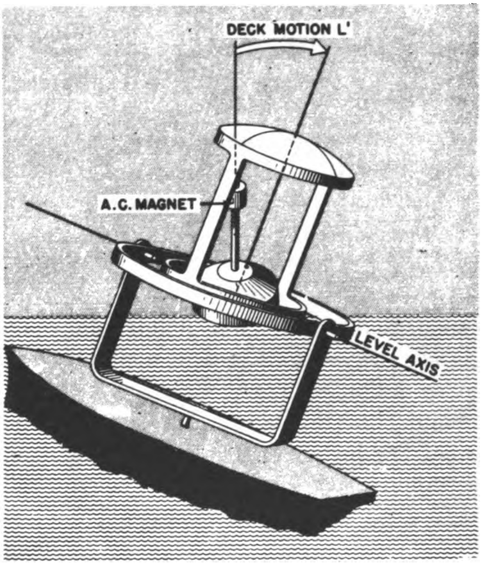
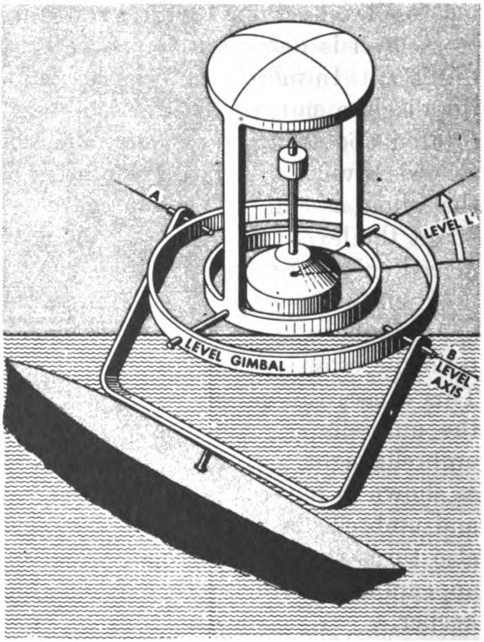


Figure 12-11.—Level error.

Figure 12-12.—Level angle after measurement.



it repositions the level gimbal so that the umbrella is again centered over the a-c magnet.

In figure 12–12 the instrument is pictured as it would look AFTER the level motor has restored the level gimbal to the horizontal. The motion of this gimbal is, therefore, a measure of L', which appears as a shaft position at the level follow-up motor.

Note that the level gimbal is mounted in the fork, which is in turn supported by the deck. Thus the level axis is always kept parallel to the deck by the level follow-up motor. The level angle is always measured in a plane containing the LOS and perpendicular to the deck. It should also be noted that by leveling the level gimbal the cross-level pivots of the inner gimbal are brought back to the horizontal. As a result, the cross-level axis is always kept horizontal as shown in figure 12–12.

How the Stable Vertical Measures Cross Level

Cross level is measured differently than level, because the cross level is defined in a vertical plane at right angles to the LOS. In figure 12–13 deck motion is all in cross level, that is, the ship is inclined so that the entire assembly is rotated about the cross level or *Zh* axis. Notice that the *Zh* axis always lies in line with the LOS, and even though the whole assembly is tilted about this axis, no tilt occurs about the level axis. Thus the umbrella in this case is displaced only by cross level.

When the umbrella receives the cross-level motion, a voltage is induced in the cross-level figure-eight coils which controls the cross-level follow-up motor shown in figure 12–10. This causes the motor to drive the cross level-gimbal until the umbrella is again centered over the magnet, and the umbrella signal again falls to zero causing the motor to stop as shown in figure 12–14. In driving the cross-level gimbal and umbrella back to the neutral position, the motor shaft also turns an amount proportional to *Zh*. And like L', *Zh* appears as a motor shaft position which is fed to the rangekeeper.

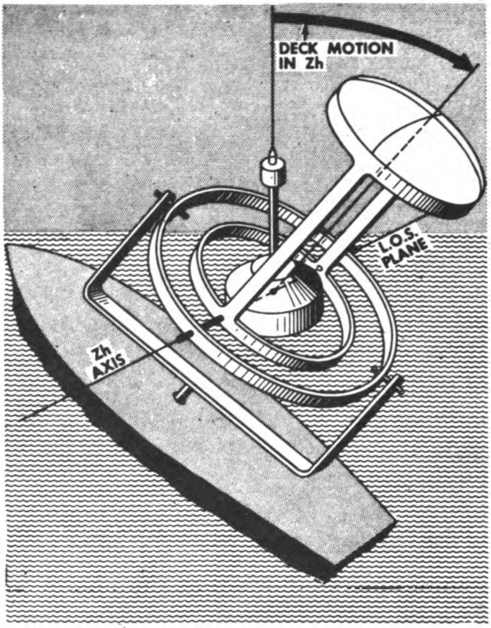


Figure 12–13.—Cross-level error.

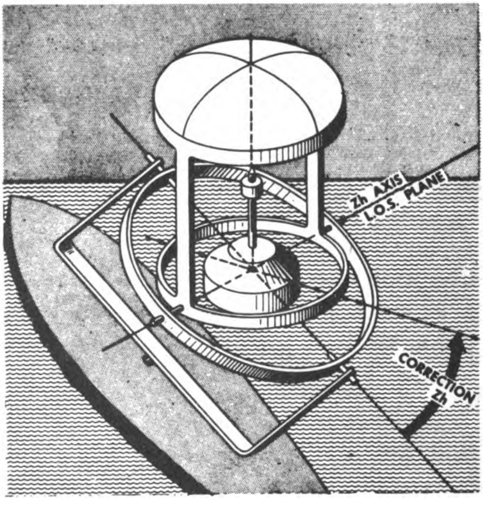


Figure 12–14.—Cross-level angle after measurement.

MEASURING L′ AND ZH AT THE DIRECTOR

In the event of stable vertical failure, the main battery director takes over the job of measuring *L′* and *Zh*. The director pointer measures *L′* and another operator called the cross-level operator measures *Zh*. These measurements are subject to human errors, but they are handy in an emergency.

The pointer and cross-level operator rotate their hand wheels to keep their crosswire on the horizon. The hand wheels, which are geared to synchro transmitters, transmit the measured quantities to the rangekeeper as shown in figure 12–15.

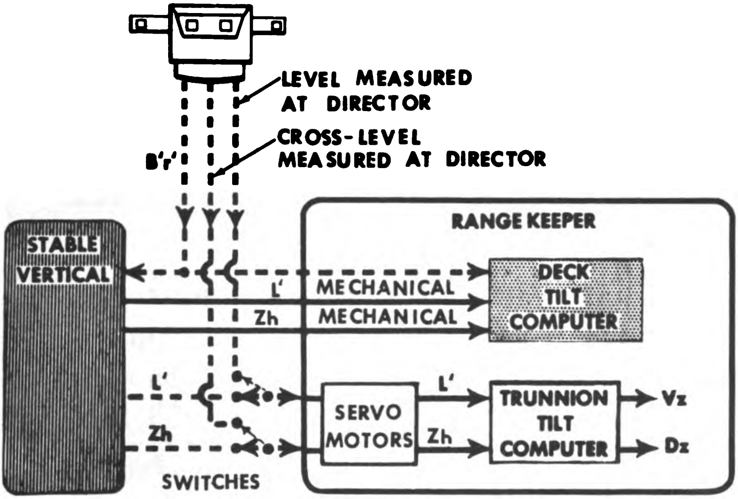
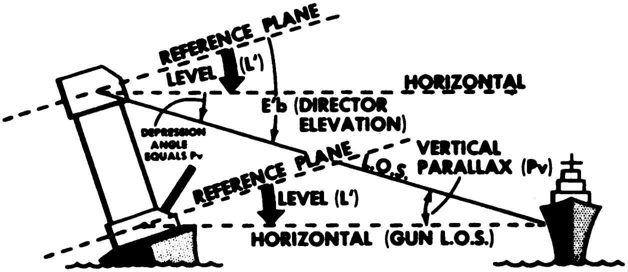


Figure 12–15.—Level and cross level measured by the director and transmitted to the rangekeeper by synchros.

A study of figure 12–15 shows that the *L′* and *Zh* quantities measured by the director are received only by the trunnion tilt section at the rangekeeper as electrical inputs. This means that if deck tilt correction is to be used, *L′* and *Zh* must be cranked in manually at the stable vertical. This is accomplished by the stable vertical operators who are observing the level and cross-level dials on the face of the stable vertical.

Let us see how the director measures L'. Imagine that the director is trained abeam as shown in figure 12–16 and the pointer and trainer are sighting down the director LOS. The offset of the pointer's telescope from the reference plane to the LOS is called DIRECTOR ELEVATION, $E'b$. When the deck is tilted as shown in figure 12–16, $E'b$ contains L' (the angle between the reference plane and the horizontal at either the director or gun) and the director SIGHT DEPRESSION ANGLE.



$L' = E'b - Pv$

Figure 12–16.—How the director measures level.

Since $E'b$ contains L', it should be apparent that all you have to do to get L' is subtract the depression angle from $E'b$. But it isn't that simple because the sight depression angle must be computed first. Look at figure 12–16 and try to visualize what would take place if the director and gun were located at the same level. The director depression angle would then equal L'. Thus the vertical distance of the director above the gun is what causes the trouble.

The difficulty is that the director and gun lines of sight are not parallel. Instead, they converge on the target at an angle known as VERTICAL PARALLAX, Pv.

A further study of figure 12–16 will indicate that the director LOS can be thought of as a transversal cutting through two parallel lines, the horizontal lines at the director and gun. Thus, the alternate-interior angles formed by the LOS and these horizontal lines are equal, i. e., the director sight depression angle is equal to *Pv*. Therefore, if *Pv* is computed in a mechanism at the director and subtracted from *E'b*, the director will transmit *L'* to the rangekeeper as desired.

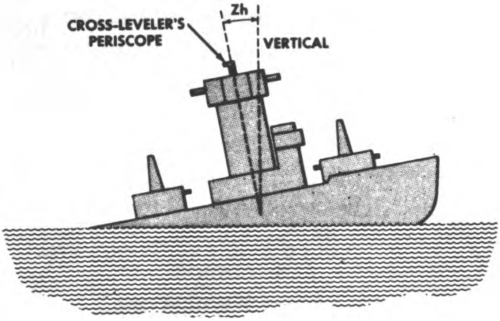


Figure 12-17.—Cross level as measured at the director.

Cross level, shown in figure 12-17, is measured by the cross-level operator as he keeps his periscope horizontal crosswire on the horizon. Since *Zh* is measured as tilt across the LOS, the cross-level sight is 90° away from the LOS as shown in figure 12-18.

The cross-level operator cranks his hand wheels as he

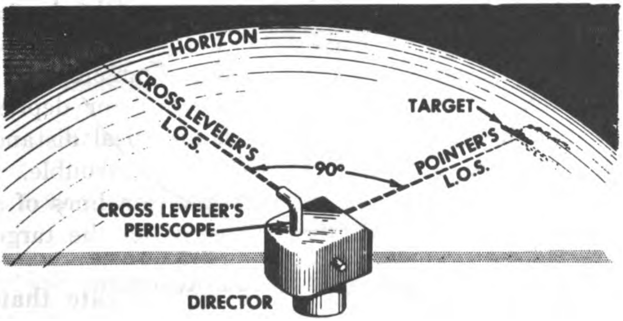


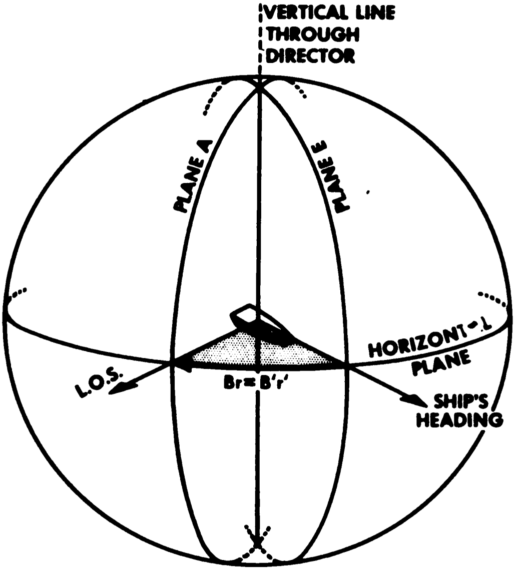
Figure 12-18.—The cross leveler's periscope is positioned 90° away from the LOS to the target.

elevates or depresses his sight to the horizon, and in doing so, positions a synchro transmitter which transmits *Zh* to the rangekeeper.

DECK TILT CORRECTION

Thus far in the study of rangekeeper computations we have assumed that the deck of the ship was level. In other words, all computations for own ship and target motion on through *Ds* and *Vs* were made up in the horizontal plane. But since the director makes its measurements of present target position in the deck plane, some method of stabilization is required to correct for deck tilt.

First consider the condition where the deck plane of the ship coincides with the horizontal plane as shown in figure 12–19.

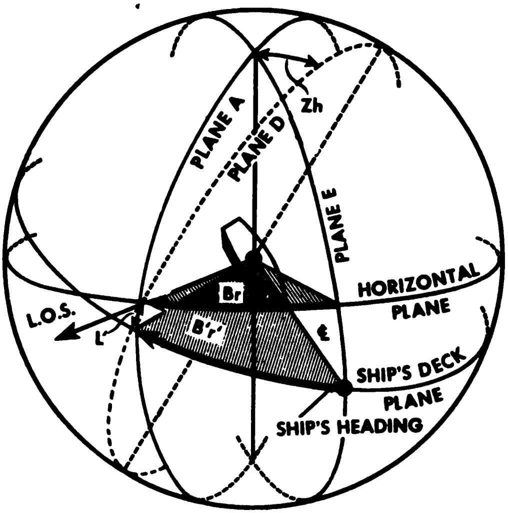


PLANE A— VERTICAL PLANE CONTAINING L.O.S.
PLANE E — VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 12–19.—Relative target bearing *Br* and director train *B'r'* are equal when the deck is horizontal.

You can see that $B'r'$ is measured from the ship's centerline at plane E around to the line of sight at plane A, and since the ship is horizontal, Br is equal to $B'r'$.

When the deck is tilted through the L' and Zh angles as shown in figure 12–20, the director must be trained farther from the ship's centerline in order to indicate relative target bearing. Obviously, Br is no longer equal to $B'r'$. Since the rangekeeper calculates ballistics in the horizontal plane, $B'r'$ must be converted to Br.



PLANE A	**VERTICAL PLANE CONTAINING L.O.S.**
PLANE E	**VERTICAL PLANE THROUGH CENTERLINE (℄) OF SHIP**
PLANE D	**PLANE PERPENDICULAR TO DECK PLANE CONTAINING L.O.S.**

Figure 12–20.—When the deck is tilted, director train $B'r'$ is no longer equal to relative target bearing Br.

The job of converting $B'r'$ to Br is performed by the deck tilt computer in the rangekeeper. Figure 12–21 shows that the deck tilt computer calculates a quantity called DECK TILT CORRECTION, $jB'r'$, which is added to $B'r'$ in a differential to give *Br*. *jB′r′* is computed from *B′r′*, *L′* and *Zh* as shown in figure 12–21.

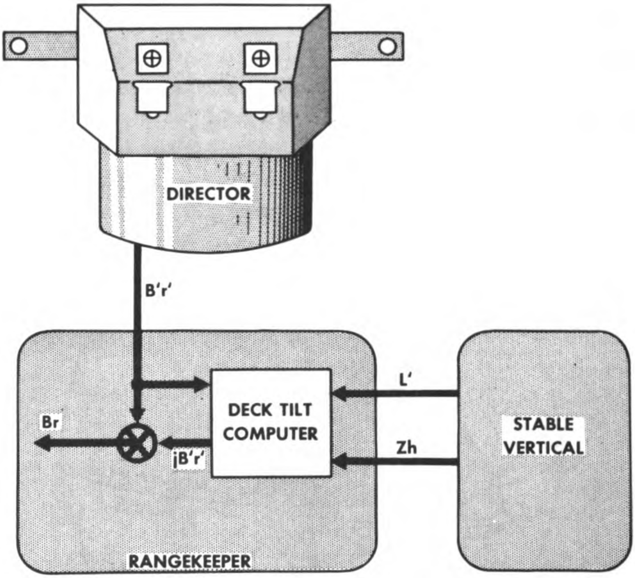


Figure 12–21.—Computing deck tilt correction.

Even though its mathematical solution is a little complicated, you can see what part *jB′r′* plays by studying figure 12–22. This figure is just a magnified view of figure 12–20, with the *jB′r′* angle drawn in.

A careful study of figure 12–22 will indicate that *jB′r′* is dependent upon both *L′* and *Zh* and the smaller these two angles are, the smaller *jB′r′* becomes. For the condition shown, *B′r′* is larger than *Br* so the deck tilt correction is subtracted from *B′r′* to give *Br*, or $Br = B'r' - jB'r'$. However, for certain other values of *L′* and *Zh*, deck tilt correction is added to *B′r′* to give *Br*. Thus, in order to correct at all times, relative target bearing is given by, $Br = B'r' + jB'r'$. In this way *jB′r′* can change its sign as *L′* and *Zh* change signs and the problem will always work out right.

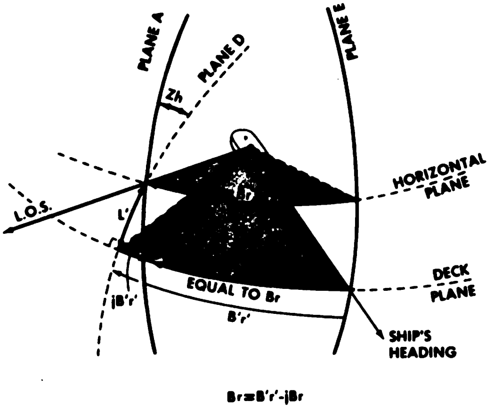


Figure 12-22.—When the deck is titled about the LOS as shown, deck tilt correction *jB'r'* is subtracted from *B'r'* to give *Br*.

To get a better picture of how the deck tilt computer fits into the fire-control system, refer to figure 12-23 and go through the diagram step by step starting at the director.

When the director is sighted on a target, it measures *B'r'*

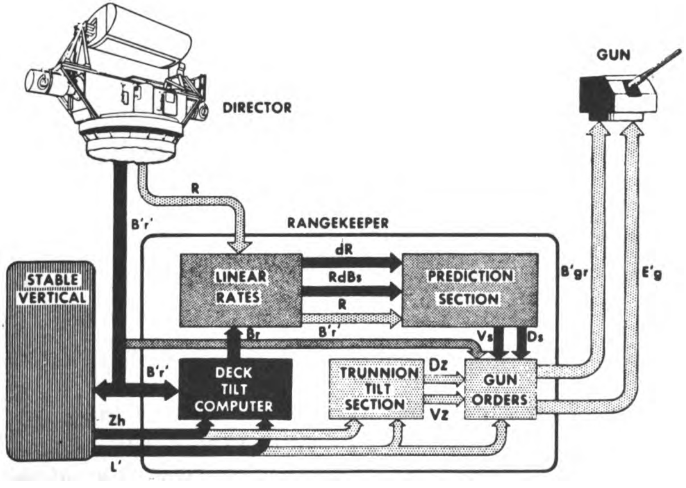


Figure 12-23.—Where the deck tilt computer fits in.

which is transmitted to the stable vertical and deck tilt computer in the rangekeeper. Then the stable vertical measures *L′* and *Zh* with reference to the LOS and transmits them to the deck tilt computer.

The deck tilt computer then makes up *jB′r′* from the *B′r′*, *L′*, and *Zh* inputs and adds it to *B′r′* in a differential to give *Br*, which establishes a true horizontal plane for the calculation of range and deflection components in the linear rate section shown in figure 12–23.

HOW THE TILTED DECK AFFECTS THE GUN

The deck tilt of a ship can be considered as having two effects on the aim of a gun. One of these effects is to elevate and depress the gun constantly as a result of the level.

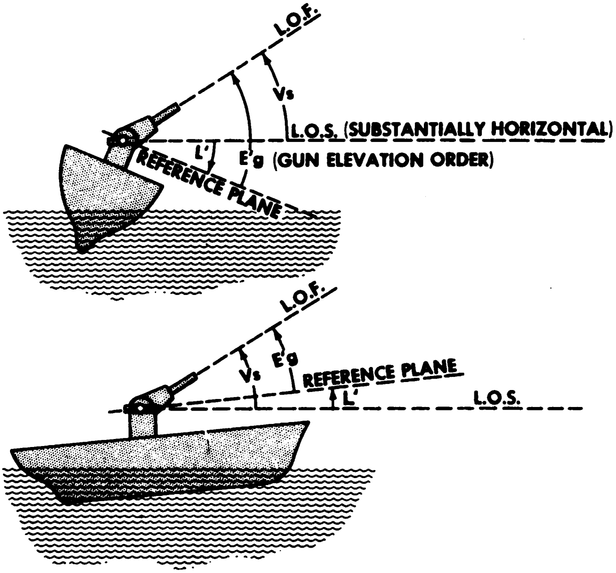


Figure 12–24.—How gun elevation is affected by the level angle.

Figure 12–24 shows that in order for the gun to remain in the LOF, *L′* is added to *Vs* to produce gun elevation order *E′g*. *E′g* is the elevation of the gun from the reference plane up to the line of fire, LOF. Thus in order to keep the gun positioned in the LOF, *L′* is continually added to V_s.

When the gun is trained abeam as shown in the upper drawing of figure 12–24, level is entirely dependent upon the roll of the ship and thus is very large. As the gun is trained ahead or astern, as shown in the lower drawing, the *L′* correction angle grows smaller and smaller because it becomes less dependent upon the roll and more dependent upon the pitch.

The second effect of the ship's movement is the tilt of the gun trunnions sideways which is caused by cross level as shown in figure 12–25.

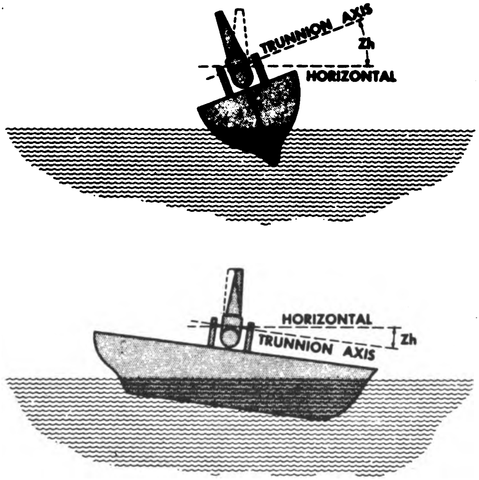


Figure 12–25.—How cross level affects the gun position.

Look at figure 12–25 and notice how the elevated gun barrel changes position when the gun trunnion axis is displaced from the horizontal by the angle *Zh*. In order to hit the target, the gun must be trained and elevated back to its dotted-line position in the figure.

The upper diagram of figure 12–25 shows that cross level is large for fore or aft shots because it is entirely dependent upon the ship's roll. This causes large trunnion tilt errors.

When the gun is trained abeam, as shown in the lower figure, *Zh* becomes smaller and smaller and so do the trunnion tilt errors.

The trunnion tilt errors must be corrected continuously and automatically in order to produce satisfactory results. This is accomplished by the stable vertical and trunnion tilt computer.

TRUNNION TILT ERRORS

Firing without regard to trunnion tilt can result in large errors, especially in deflection. Roughly speaking, the deflection error in mils for surface fire is approximately one-third of the product of *Vs* and *Zh*. Thus, if the gun is fired at an elevation of 20° with the deck tilted so that *Zh* is 6°, the deflection error would be about 40 mils; that is

$$\frac{20 \times 6}{3} = 40 \text{ mils.}$$

At a firing range of 15,000 yards this is equivalent to a deflection error of 600 yards, or approximately one-third of a mile.

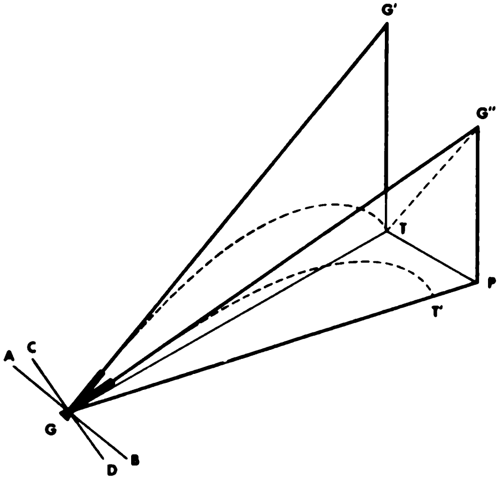


Figure 12–26.—Trunnion tilt errors.

You can see the effect of trunnion tilt for surface fire in figure 12–26. GG' represents the axis of the bore of the gun when the trunnion axis AB is horizontal. In this case, if we assume that there is no deflection and no drift present, the trajectory GT will lie in the plane $GG'T$. The angle of elevation for the gun to hit the target will be TGG'.

Now if the axis of the trunnion is tilted through the angle AGC, the axis of the bore of the gun will lie along the line GG instead of GG', and the angle $G'TG''$ will be equal to the trunnion tilt AGC. The trajectory will now lie in the vertical plane $GG''P$ through the axis of the bore of the gun, GG''. Therefore, the projectile will land at the point T':

This shows us that two errors result in figure 12–26. The first error is the deflection error TP and the second error is a range error PT', which is caused by the decreased gun elevation angle. Therefore, the projectile will fall away from the target by the amount TT'.

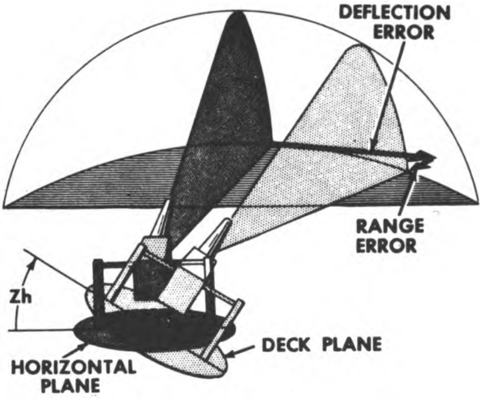


Figure 12–27.—Effect of trunnion tilt.

A study of figure 12–27 can tell you several things about trunnion tilt errors. First, that as Zh increases, the elevation of the gun increases which increases the range error.

Figure 12–27 also shows that the deflection error will vary with the gun elevation and range. Deflection errors due to trunnion tilt will increase with range. At point blank range where the trajectory is flat, the deflection error will be zero regardless of how large trunnion tilt becomes for the bore axis will still point in the same direction no matter how far the gun trunnions are rotated.

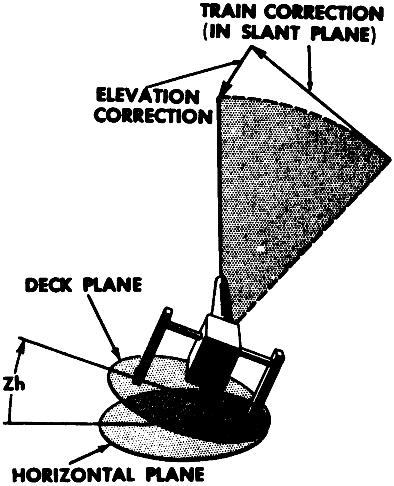


Figure 12–28.—Correction for trunnion tilt.

In order to correct the errors shown in figure 12–27, the gun must be trained uphill to the left and depressed back on the target as indicated in figure 12–28. Although the error caused by trunnion tilt is largely a deflection error, its correction requires motion of the gun in both train and elevation.

These corrections are called train correction *Dz* in the slant plane and elevation correction *Vz* in a plane perpendicular to the deck through the bore axis.

Trunnion Tilt Errors and Corrections with No Deflection

The only way you can thoroughly understand trunnion tilt errors and their corrections is to study how they vary under different conditions.

Figure 12–29 shows the horizontal and vertical planes. The horizontal plane is always stationary and remains tangent to the earth's surface. The vertical plane is always perpendicular to the horizontal plane, and always contains the LOS; it shifts with the relative target bearing angle, *Br*. In the figure the gun is at *O* and the target at *T*, making LOS correspond to the line *OT*. Since no deflection is present, the director and gun lines of sight coincide.

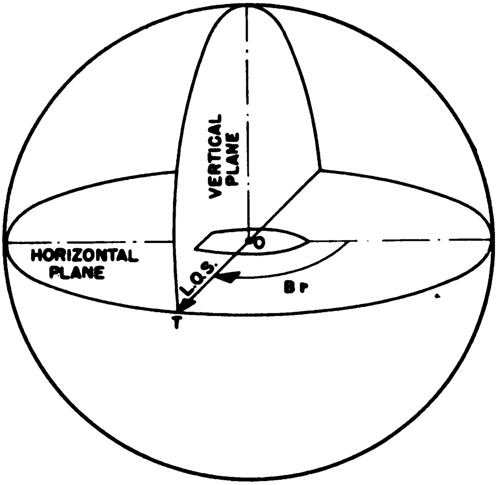


Figure 12–29.—Basic spherical diagram.

Although *Br* is used to determine the LOS relative to the ship's head, it is not shown in figure 12–30. It should be borne in mind, however, that the LOS is the reference for measuring *L′* and *Zh*.

In figure 12–29 the deck plane corresponds to the horizontal plane, but in figure 12–30 the deck plane is tilted by the angle *Zh* about the line *OT*, the cross-level axis (LOS). Therefore, if the bore axis of the gun were elevated in the vertical plane with the deck horizontal, it would be carried over to the vertical plane perpendicular to the deck, which is displaced from the true vertical plane by the angle *Zh*. Thus, the LOF will be displaced from the vertical plane containing the LOS.

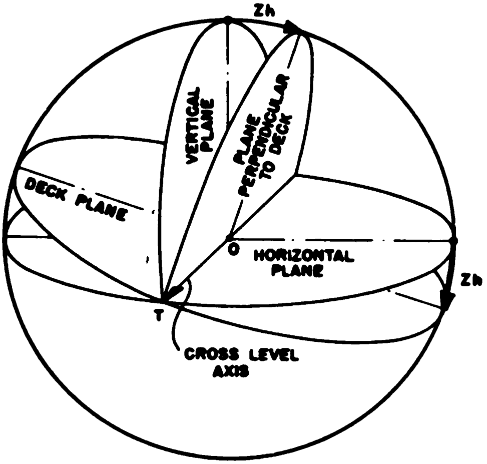


Figure 12–30.—Cross level (surface problem).

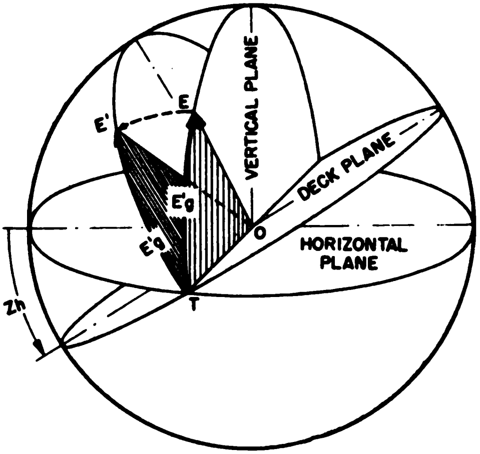


Figure 12–31.—Error due to trunnion tilt with no deflection.

This displacement of the LOF can be understood from figure 12–31. The line *OE* represents the initial or computed position of the LOF, with no deflection present. The gun initially lies in the vertical plane containing the line of sight *OT*, and is elevated above the deck plane by the angle *E'g* to the position *OE*.

Now assume that the deck plane becomes inclined about the axis *OT* by an amount equal to cross level as shown in figure 12–31. This will swing the LOF from *OE* to *OE'*, lowering the gun aim and also creating a large angular error in deflection. The inclination of the deck will have no effect upon the angle the gun is elevated above the deck and the gun will be firing at a false point *E'* until the computed angle *E'g* is corrected.

The left diagram in figure 12–32 illustrates the corrections for the errors which were illustrated in figure 12–31. Let us correct the deflection error first. You know that the gun's roller path lies in the deck plane so that when it trains to get from its present position *E'* to the computed point of aim *E*, the projection of the LOF on the sphere will swing in an arc parallel to the deck plane. This motion is represented by the train correction *a*, which is an angular correction in the slant plane.

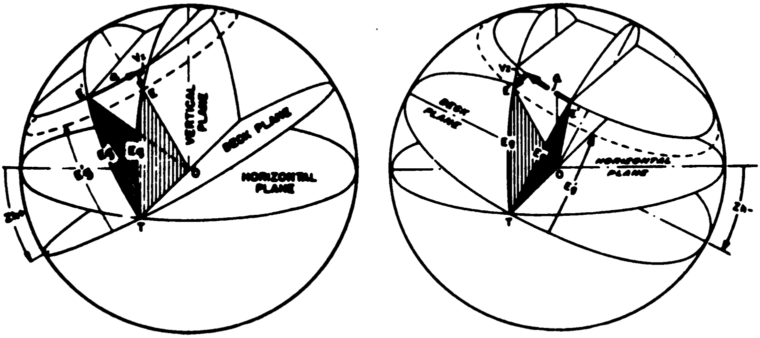


Figure 12–32.—Correction for tunnion tilt with no deflection.

This train correction *a*, is not enough to correct completely the gun for *Zh* because it leaves the gun axis above the point *E*. The elevation correction *Vz* is required in solving the problem.

The right drawing of figure 12–32 illustrates the corrections for a *Zh* of the opposite or negative direction. When no sight deflection is present, the elevation correction *Vz* is always down.

Figure 12–33 repeats the situation shown in the right drawing of figure 12–32 with an additional angle shown. It shows how the train correction *a* in the slant plane is converted to the gun train correction *Dz* in the deck plane. In figure 12–33 *Zh* caused the gun bore to move to point *E′*. A study of the figure shows that the train correction *a* and the elevation correction *Vz*, both in the slant plane, have restored the gun to position *E′* in space.

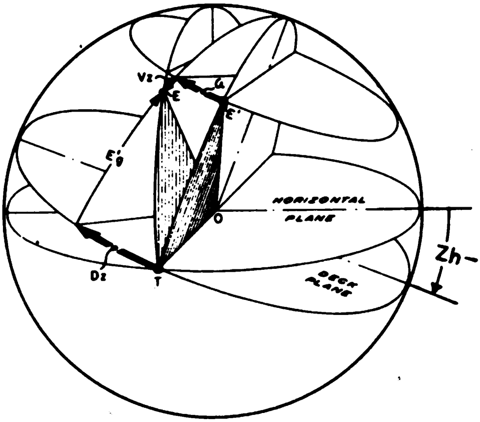


Figure 12–33.—Converting train correction *a* in the slant plane into train correction *Dz* in the deck plane.

The train correction *a* presents a problem because it is located in the slant plane containing the LOF as shown in figure 12–33. The gun must be trained through the angle *Dz* in the deck plane of the ship to correct for the train error *a* in the slant plane.

Figure 12–34 shows how the train correction *a* and elevation correction *Vz* vary with the gun elevation. If the gun axis is lying along *OT*, no correction is required, but as the gun elevates both *a* and *Vz* grow larger. Since gun elevation depends on sight angle *Vs*, the trunnion tilt corrections increase as sight angle increases and *Dz* will also increase.

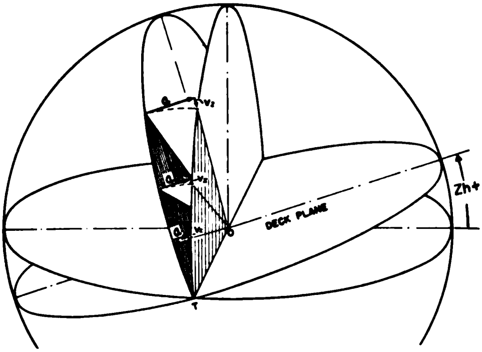


Figure 12–34.—The correction *a* and *Vz* increases as sight angle increases.

Trunnion Tilt Correction with Sight Deflection Present

The introduction of sight deflection *Ds* makes the problem more complicated in that *Dz* and *Vz* vary as *Ds* varies. Therefore, trunnion tilt corrections must take *Vs* and *Ds* into account when being computed.

Figure 12–35 shows the situation where the deck is hori-

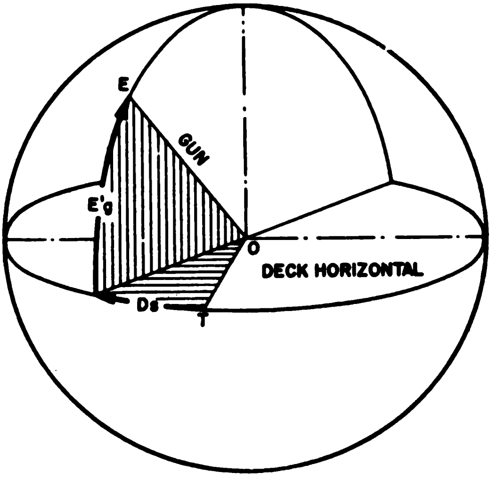


Figure 12–35.—Sight deflection causes no change in the position of the gun trunnions when the deck is horizontal.

zontal. Sight deflection *Ds* in the horizontal plane, which now coincides with the deck plane is shown as well as the gun elevation above the deck plane, *E′g*. *E′g* equals the gun elevation above the horizontal, *Eg*, since the deck is horizontal.

Figure 12–36 shows the gun position when the deck is tilted by *Zh*, and *Ds* is present. A study of the diagram will tell you that two things happened to the gun position. First, the bore axis or the gun has been deflected to the left and elevated from point *E* to *E′*, and second, the train of the gun in the deck plane remains essentially the same.

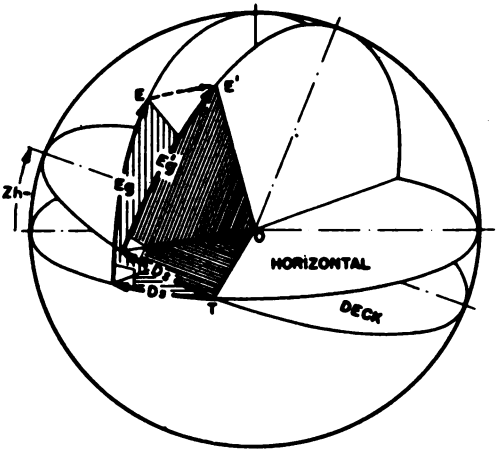


Figure 12–36.—Effect of cross level with sight deflection present.

The corrections necessary to bring the gun back to the computed point *E* are shown in figure 12–37. *Dz* takes care of angular train correction *a* in the slant plane and *Vz* corrects the gun elevation. Notice that *Dz* correction is about the same size as when there was zero deflection, but *Vz* is much larger because the gun is positioned farther uphill as a result of *Ds*.

One new quantity is shown in figure 12–37. It is called DECK DEFLECTION *Dd′*. Deck deflection is the total amount the gun must be trained in the deck plane to correct for

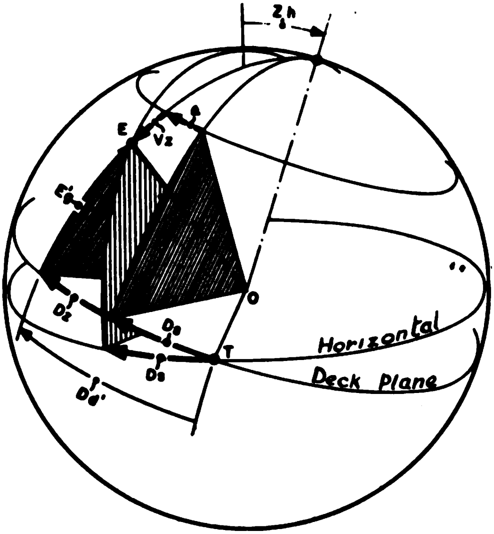


Figure 12-37.—Corrections for trunnion tilt with deflection present.

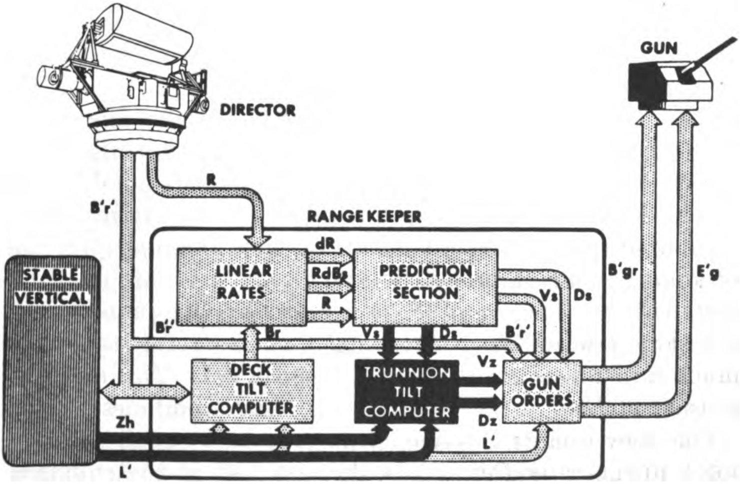


Figure 12-38.—Where the trunnion tilt computer fits in.

trunnion tilt plus all ballistics, and since *Ds* contains the corrections for all ballistics, and *Dz* is the train correction for trunnion tilt, then $Dd' = Ds + Dz$.

Effect of Level on Trunnion Tilt

The effect of level on trunnion tilt is so slight that it is neglected altogether. However, it is very important to understand that level elevates and depresses the gun and must be allowed for. Therefore, level is added directly to *Vz*, in calculating $E'g$. L' hardly affected Dd' and is sometimes ignored. However, large values of L' will have the effect of making *Dz* slightly over-corrected when *Dz* is large.

To sum it up, the trunnion tilt corrections vary with *Vs*, *Ds*, *Zh*, and to a small extent with level, L'. The trunnion tilt computer shown in figure 12–38 takes *Vs*, *Ds*, *Zh*, and L' as inputs to produce the elevation correction *Vz* and the train correction *Dz*. The outputs of the trunnion tilt computer are *Vz* and *Dz* and are combined with *Vs*, *Ds*, and $B'r'$ in the gun order section, which transmits the proper $E'g$ and $B'gr$ to the gun.

Trunnion Tilt Computations

A typical trunnion tilt computer is shown in figure 12–39. It mechanically solves for *Dz* and *Vz*. The empirical equation for the computation of *Dz* is: $Dz = [f1\ (L')\, f1\ (Vs) + KVs]\ [Zh + K1\ (L'Ds)]$. This formula shows that the calculation of *Dz* involves the multiplication of two main quantities.

The $f(L')\ f(Vs)$ computer in the upper left-hand corner of figure 12–39 is a computing multiplier which derives functions of two quantities by means of cams and multiplies one function by the other. As shown in figure 12–39, the $f(L')$ cam and the $f(Vs)$ cam are positioned by the quantities L' and *Vs*, respectively. The output of the computer is the product of the cam outputs, $f(L')$ and $f(Vs)$. This quantity is then applied to differential *D*1, which combines it with the quantity *KVs* obtained from the sight angle gearing. The output of *D*1 represents the first half of the equation, that is $f(L')\ f1(Vs) + KVs$.

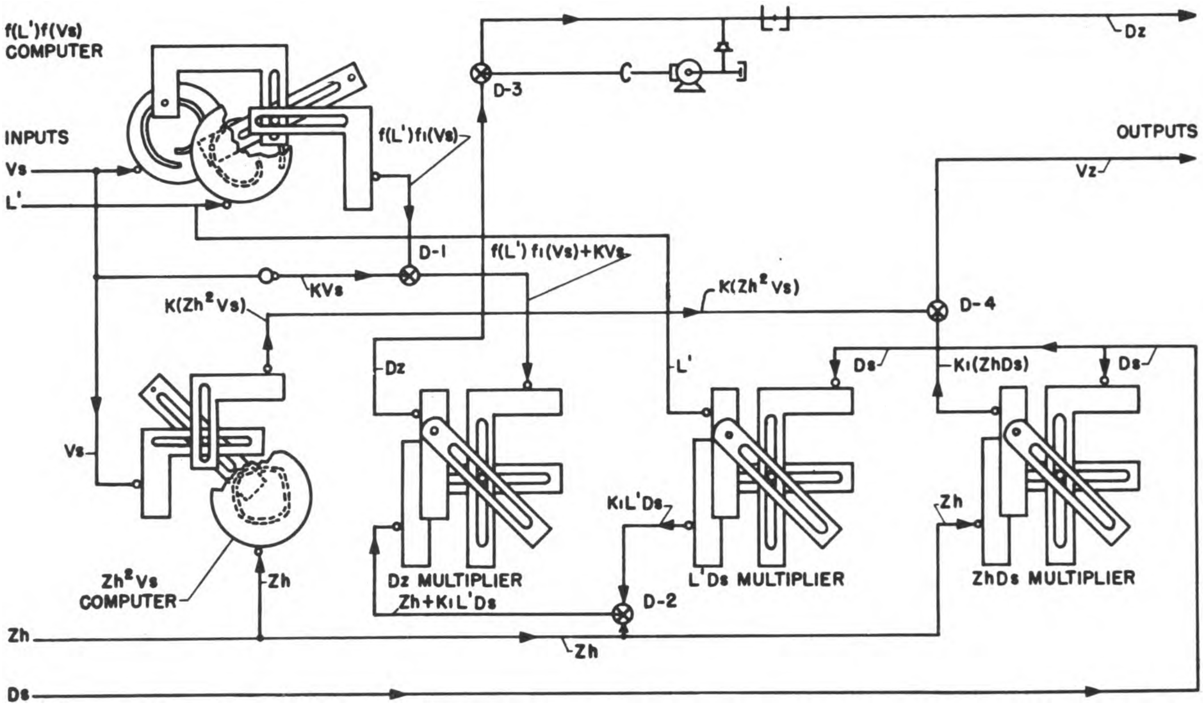


Figure 12-39.—Typical trunnion tilt computer.

The $L'Ds$ multiplier is shown in the lower central part of the figure where the product of L' and Ds is obtained, modified by a constant in the gearing, and then added to Zh in $D2$. The output of $D2$ represents $Zh+K1\ (L'Ds)$, the second half of the Dz equation.

The Dz rack type multiplier shown in figure 12–39 performs the final operation in the solution of the Dz equation. Differentials $D1$ and $D2$ provide the rack inputs. The outputs of the multiplier, Dz, is amplified in torque by the Dz follow-up motor shown in the upper central part of the figure.

The trunnion tilt computer of figure 12–39 has the additional task of solving for the elevation trunnion tilt correction, Vz, from the following formula. $Vz=-K\ (Zh^2 \cdot Vs)-K1\ (Zh \cdot Ds)$.

The Zh^2Vs computer is shown in the lower left-hand corner of figure 12–39. The single cam in this computing multiplier is cut to produce the square function of a quantity. Positioned by Zh, the cam computes the quantity Zh^2, which is multiplied by Vs, the rack input of the computer. The multiplier output drives through gear ratios to become $K(Zh^2 \cdot Vs)$, the first part of the equation. In applying this quantity to differential $D4$, the direction of rotation of the input is selected to give the quantity a NEGATIVE SIGN.

The $ZhDs$ multiplier is shown in the lower right-hand corner of figure 12–39. As can be seen in the figure, the input racks of the $ZhDs$ multiplier are positioned by gearing which represents the quantities Zh and Ds. To form the last part of the Vz equation the output of the $ZhDs$ multiplier is driven through gear ratios resulting in the quantity $K1(Zh \cdot Ds)$. In differential $D4$ this quantity is combined with the first part of the equation to complete the computation of Vz.

DECK TILT COMPUTATION

The equation solved for by the deck tilt group is:

$$jB'r'=K\ [K1(L'^2-Zh^2)\ \sin 2B'r'-Zh(L'+L'\ \cos 2B'r')]$$

Although this equation appears to be complicated it is easily solved by means of two component solvers, two screw-type multipliers, and a few differentials as shown in figure 12–40.

The steps taken by the rangekeeper in solving this modified equation are more easily shown if the equation is put in the following expanded form:

$$jB'r' = K[K1(L'+Zh)\times(L'-Zh)\sin 2B'r' - Zh(L'-L'\cos 2B'r')]$$

The first operation in solving the above equation is to compute the two quantities, $(L'-Zh)\sin 2B'r'$ and $L'\cos 2B'r'$. This is done by component solvers. The angle, $2B'r'$, appearing in both quantities, is a result of modifying the true equation. It is obtained by using a two-to-one gear ratio between the $B'r'$ dials and the vector gears of the component solvers, causing the vector gears to move through an angle having twice the value of $B'r'$.

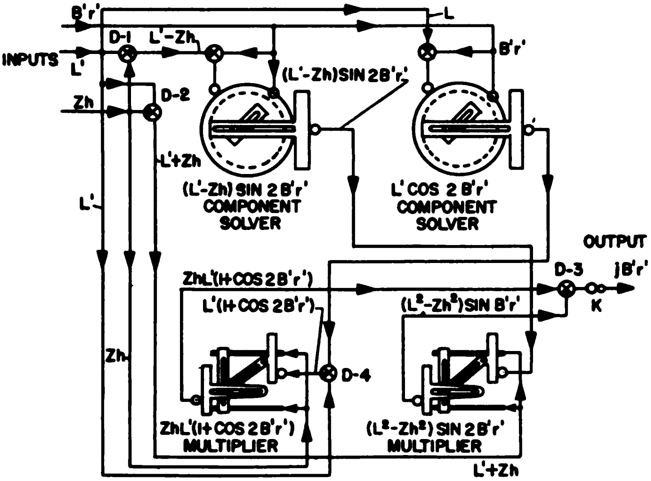


Figure 12–40.—Deck tilt computer.

The component solver in the upper left-hand corner of figure 12–40 computes $(L'-Zh)\sin 2B'r'$ in the following manner. Cross level Zh is subtracted from L' in differential $D1$. The difference, $L'-Zh$, drives through the compensating differential to rotate the spiral cam of the $(L'-Zh)\sin 2B'r'$

component solver, thereby positioning the pin radially at a distance proportional to $L'-Zh$.

The vector gear of the $L'-Zh \sin 2B'r'$ component solver is adjusted so that the output represents sine values. $B'r'$ drives through the two-to-one gear ratio and positions the slot in the vector gear at an angle that is equal to $2B'r'$.

The output slide of the component solver, positioned by the spiral cam and the vector gear, represents $(L'-Zh) \sin 2B'r'$.

The component solver in the upper right-hand corner of figure 12–40 computes $L' \cos 2B'r'$ in the following manner. Level L' drives through the compensating differential and rotates the spiral cam of the $L' \cos 2B'r'$ component solver to position the pin radially at a distance proportional to L'.

The vector gear of the $L' \cos 2B'r'$ component solver is adjusted so that the output represents cosine values. As in the $(L'-Zh) \sin 2B'r'$ component solver, $B'r'$ positions the vector gear at an angle equal to $2B'r'$. The output of this component solver represents $L' \cos 2B'r'$.

The rest of the deck tilt equation is solved by two screw-type multipliers and three differentials. The output of the $(L'-Zh) \sin 2B'r'$ multiplier is shown in the lower right-hand corner of figure 12–40. L' is added to Zh in differential $D2$, and the resultant quantity is used to position the screw input of the multiplier. The output is $(L'+Zh)(L'-Zh) \sin 2B'r'$, or $(L'^2-Zh^2) \sin 2B'r'$. This quantity, multiplied by a constant $K1$, obtained through suitable gear ratios, is the first part of the equation for $jB'r'$.

The output of the $L' \cos 2B'r'$ component solver in the lower left-hand corner of figure 12–40 is added in differential $D4$ to L', and the resultant quantity $(L'+L' \cos 2B'r')$ is used to position the rack input of the $Zh(L'+L' \cos 2B'r')$ multiplier. The screw input to this multiplier is rotated by Zh. The output is Zh multiplied by $(L'+L' \cos 2B'r')$ to produce the second part of the equation for $jB'r'$.

$Zh(L'+L' \cos 2B'r')$ is subtracted from $K1(L'^2-Zh^2) \sin 2B'r'$ in differential $D3$ and the result is multiplied by a gearing constant, K. The quantity $jB'r'$ obtained in the deck tilt computer is then amplified in torque by the $jB'r'$ follow-up.

QUIZ

1. Br is equal to director train only when
   a. range is constant
   b. deck is level
   c. L' is at a positive value
   d. Zh is present
2. Deck tilt is measured with respect to the
   a. line of sight
   b. ship's centerline
   c. level axis
   d. cross-level axis
3. Relative target bearing is equal to the sum of
   a. Zh and $B'r'$
   b. L', Zh and $B'r'$
   c. Dz and $B'r'$
   d. $B'r'$ and $jB'r'$
4. The trunnion tilt correction is used to
   a. establish a horizontal plane for the rangekeeper
   b. establish a reference plane for the stable vertical
   c. modify the signals to the stable vertical
   d. modify the orders to the guns
5. Who positions the stable vertical in relation to LOS?
   a. Director control officer
   b. Director pointer
   c. Director trainer
   d. Rangefinder operator
6. Which one of the following inputs must the stable vertical have to measure level and cross level with respect to the LOS?
   a. $jB'r'$
   b. R
   c. Br
   d. $B'r'$
7. The umbrella signal pick-up of the stable vertical is mounted
   a. above the gyro
   b. around the gyro
   c. under the gyro
   d. on the LOS side of the gyro
8. The signal voltage of a stable vertical is induced in the
   a. magnet coils
   b. gyro wheel
   c. gimbal rings
   d. umbrella coils

9. When the level and cross-level follow-up motors reposition the umbrella over the magnet, the signals to the motors become zero when
   a. the level gimbal is level
   b. the cross-level gimbal is level
   c. both the level and cross-level gimbals are level
   d. the supporting fork is positioned through the *B'r'* angle
10. The follow-up motors in the stable vertical reposition the umbrella, and also
   a. drive the same amount into the rangekeeper
   b. correct for director train
   c. correct for director elevation
   d. drive the gyro by the same amount
11. When measured at the director, *L'* and *Zh* are measured
   a. in and across the LOF
   b. in and across the LOS
   c. with respect to the ship's centerline
   d. by the pointer and trainer
12. Normally the deck tilt computer receives the *L'* angle from the
   a. stable vertical by mechanical linkage
   b. stable vertical by synchros
   c. director by mechanical linkage
   d. director by synchros
13. The deck tilt computer is used to determine
   a. *Zh*
   b. *L'*
   c. *B'r'*
   d. *Br*
14. The angle formed by the LOF and the LOS is equal to the *Vs* when
   a. *L'* equals *Zh*
   b. *Br* equals the LOS
   c. the LOS is on the centerline
   d. the deck plane is horizontal
15. The trunnion tilt train correction, *Dz*, is measured in the
   a. slant plane
   b. horizontal plane
   c. vertical plane
   d. deck plane
16. Both *Vz* and *Dz*
   a. increase as *Vs* increases
   b. decrease as *Vs* increases
   c. are independent of *Vs*
   d. are contained in *Vs*

17. The range error due to trunnion tilt increases with
    a. an increase in Zh
    b. an increase in L'
    c. a decrease in L'
    d. a decrease in Zh

18. In the trunnion tilt computer the functions $f(L')$ and $f(VS)$ are
    a. differential outputs
    b. multiplier constants
    c. cam outputs
    d. serve quantities

19. Which one of the following quantities is NOT an input to the trunnion tilt computer?
    a. Vs
    b. Ds
    c. $B'r'$
    d. L'
    e. Zh

20. In the deck tilt computer, the quantity $2B'r'$ is determined by a
    a. cam
    b. gear ratio
    c. differential
    d. vector solver

21. The $Zh^2 Vs$ computer or the trunnion tilt mechanism is actually a
    a. rack-type multiplier
    b. double-cam computing multiplier
    c. converted component solver
    d. single-cam computing multiplier

22. From the $jB'r'$ formula, $L' - L' \cos 2B'r'$ is the input to a
    a. differential
    b. multiplier
    c. component solver
    d. gear ratio

CHAPTER 13

GUN ORDERS

In the study of fire control it is easy to overemphasize the function of certain equipment such as the rangekeeper by not fully appreciating how the equipment fits into the complete system.

Every fire-control system used for the control of the main battery is comprised of a group of instruments working together to produce gun train order, *B'gr*, and gun elevation, *E'g*, both of which position the gun to hit the target. To bring you up to date on the information that flows into these gun orders, a short review discussion will be given here.

In the study of a fire-control system and in the location of an error which might be present in the system, there are three basic elements of gun orders which you must thoroughly understand. These quantities are the angles which are added together to produce the gun orders. These angles can be classified into three basic groups as shown in figure 13–1.

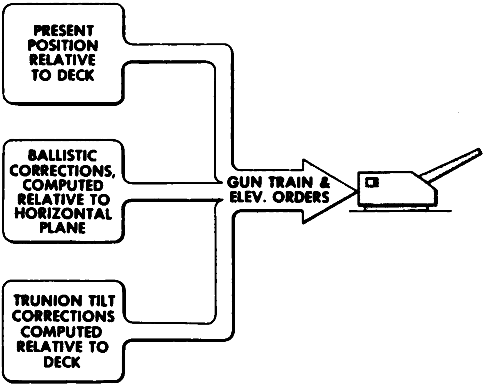

PRESENT POSITION RELATIVE TO DECK
BALLISTIC CORRECTIONS, COMPUTED RELATIVE TO HORIZONTAL PLANE
TRUNION TILT CORRECTIONS COMPUTED RELATIVE TO DECK
GUN TRAIN & ELEV. ORDERS

Figure 13–1.—Basic elements of gun train and elevation orders.

The first group, upper block in figure 13–1, is measured by the director. It measures the present target position relative to the deck plane of the ship by its angle of train, *B′r′*, from the ship's centerline as shown in figure 13–2. You already know the LOS from own ship to target is the baseline for all calculations performed by the rangekeeper and the stable vertical. Therefore, *B′r′* is transmitted to the stable vertical and the rangekeeper to establish the LOS.

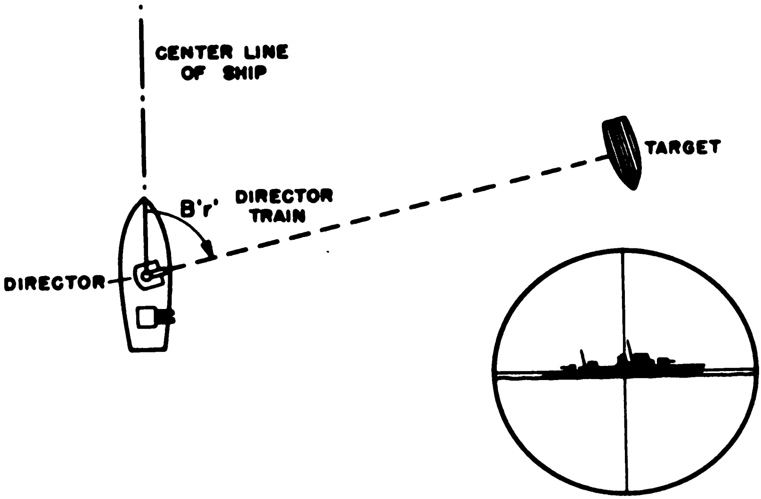


Figure 13–2.—Present target position is measured by director train.

Director elevation, *E′b*, can also be measured by the director in a plane perpendicular to the deck plane, through the LOS. However, *E′b* is not always measured by the director. As you know, the stable vertical takes care of *E′b* with the measurement of *L′*. Those main battery directors that measure *E′b* can measure *L′* in case of stable vertical failure. *L′* is contained in the angle *E′b*, and is measured by the director pointer as he keeps the sight on the target.

The final measurement needed by the director to establish the target's present position relative to own ship is range, which is measured either by the rangefinder or radar.

The second step in computing the gun orders is the calculation of the second group of basic angles, the ballistic corrections, which are computed relative to the horizontal plane. (See fig. 13–1.) The stable vertical establishes the horizontal plane with its level and cross-level outputs. The quantity $B'r'$ is converted to Br in the deck-tilt section of the rangekeeper by the quantity $jB'r'$ (deck-tilt correction). You will recall that $jB'r'$ is made up in the rangekeeper from the director and stable vertical inputs $B'r'$, L' and Zh. Once the horizontal plane is established with Br, computations for own ship and target motion, wind corrections, drift, I. V. loss, and on through Vs and Ds, are solved to complete the second step.

The third and last step is the calculation of trunnion-tilt corrections relative to the deck (bottom block of figure 13–1) which is accomplished by the rangekeeper with the aid of the stable vertical. Also feeding into the gun orders is the quantity L', one of the stable vertical outputs, to make up $E'g$.

Now if all this information is put together, you will come up with gun orders.

GUN TRAIN ORDER

Gun train order is the result of an addition of the three basic angular quantities Dz, Ds, and $B'r'$. As shown in figure 13–3, gun train order is equal to

$$B'gr = Ds + Dz + B'r',$$

or, since Ds and Dz are added in the rangekeeper to give deck deflection, $D'd$, you can write

$$B'gr = D'd + B'r'.$$

When the deck is level, $B'gr$ is equal to the sum of Ds and $B'r'$ because no trunnion tilt is present and Dz is zero.

As indicated in figure 13–3, gun train order positions the gun to the line of fire. You will recall that the line of fire lies in a plane drawn through the bore axis of the gun perpendicular to the deck of the ship.

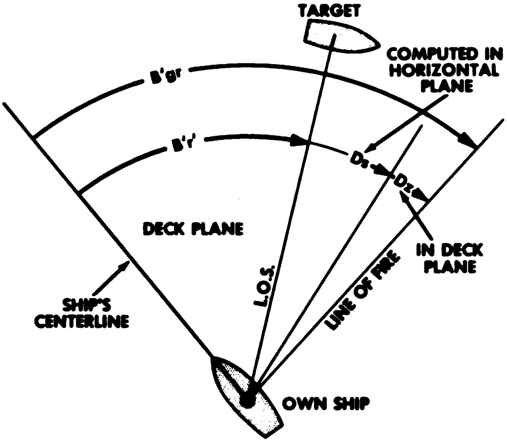


Figure 13-3.—Gun train order.

Figure 13-4 shows how the quantities manufactured in the rangekeeper and director are combined to produce *B′gr*.

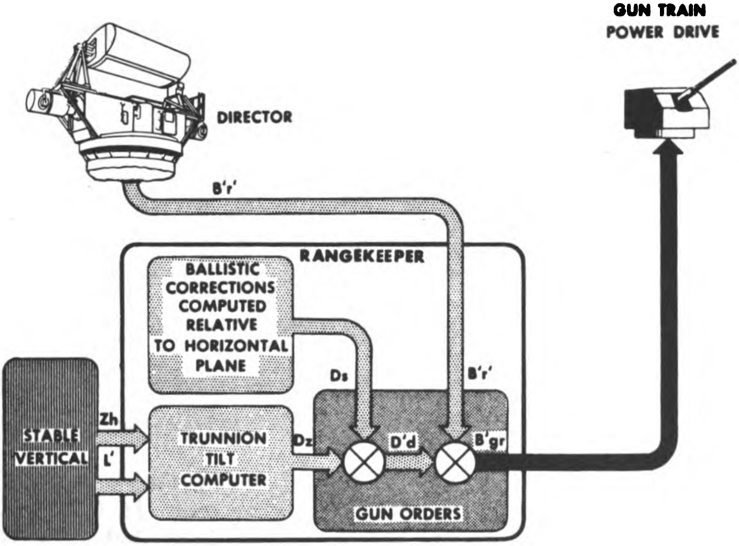


Figure 13-4.—How the rangekeeper manufactures *B′gr*.

Ds and *Dz* are added in one differential to give *D′d*; then this quantity of *D′d* is added in another differential to *B′r′* to give *B′gr*. *B′gr* is then transmitted by synchro transmitters to the gun to control the power drive and position the gun in response to the transmitted signal. These power drives may consist of hydraulic or electric mechanisms and motors, or a combination of both.

HORIZONTAL PARALLAX

Normally, the director and gun are separated by a horizontal distance, which means their lines of sight will not be the same. This separation between the director and gun makes a difference in determining the direction of the target relative to the line of fire, which brings up the term HORIZONTAL PARALLAX.

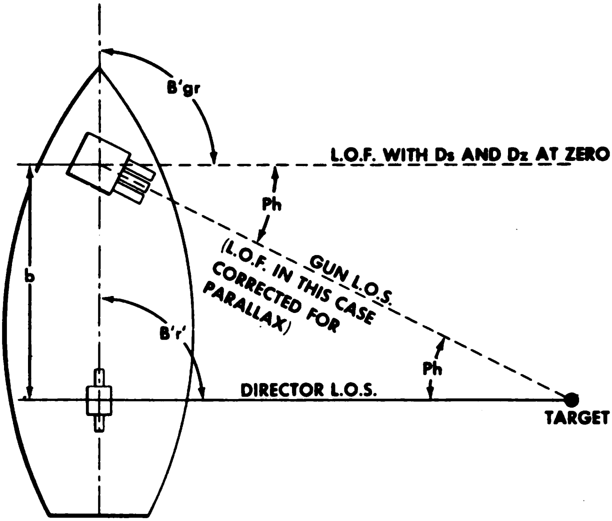

B′gr
L.O.F. WITH Ds AND Dz AT ZERO
Ph
GUN L.O.S.
(L.O.F. IN THIS CASE CORRECTED FOR PARALLAX)
b
B′r′
Ph
DIRECTOR L.O.S.
TARGET

Figure 13–5.—Horizontal parallax with target abeam.

As shown in figure 13–5, the effect of horizontal parallax is greatest when the target is directly abeam. In this case assume that the ballistics are such that sight deflection is zero, and that the deck and trunnion-tilt corrections are zero. Then, since $B'gr=B'r'+Ds+Dz$, gun train order would equal $B'r'$ because $B'gr=B'r+0+0$.

But if the gun was trained through the angle $B'gr$, the projectile would not hit the target, as shown by figure 13–5. Therefore, to score a hit the gun must be trained around farther, through the horizontal parallax angle, *Ph*.

Parallax angle may be thought of in two ways. The angle at the gun between the gun LOS and a line running through the gun parallel to the director LOS, or the angle at the target between the gun and director LOS. It is clear from figure 13–5 that these two angles are equal.

It should also be clear from figure 13–5 that the value of *Ph* in mils is the base length, *b*, in yards divided by the range in thousands of yards. That is, $Ph=\frac{b}{R}$ mils. This simple formula holds good only when the target is directly abeam. It should be obvious that *Ph* will be zero for a target directly ahead or astern.

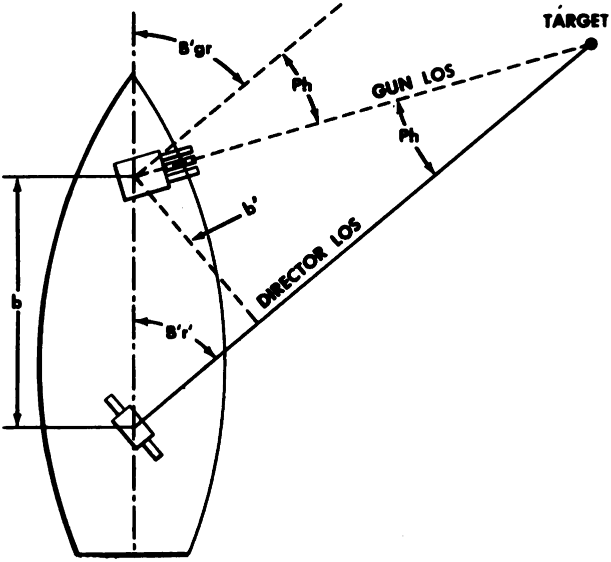


Figure 13–6.—How horizontal parallax is calculated for any train angle.

Figure 13–6 shows parallax for a target between these two positions. Here the parallax angle is:

$$Ph=\frac{b'}{R} \tag{1}$$

You compute b' from the triangle formed by b, b' and $B'r'$:

$$b'=b \sin B'r' \tag{2}$$

or

$$b'=b \sin B'gr. \tag{3}$$

The use of $B'r'$ or $B'gr$ depends upon whether the computation is being performed at the director or the gun.

The parallax equation can now be solved by substituting the value of b' of (3) in (1), which gives

$$Ph=\frac{b \sin B'gr}{R}$$

or

$$Ph=b \sin B'gr \frac{1}{R}$$

where R in the equation may be either generated present range cR or advance range $R2$ depending upon the system.

If all guns were the same distance from the director, the parallax angle could be computed in the plotting room and included in gun train orders. But since they are not, the correction for parallax is computed separately at each gun.

In most surface fire-control systems, inverse present range $\frac{1}{R}$ is transmitted to the guns from the rangekeepers in plot by synchro, and the rest of the computation is performed in a PARALLAX CORRECTOR at the gun.

The parallax corrector is nothing more than a component solver. Inverse range, sometimes called parallax range, is received at the turret by synchro and becomes the speed input of the component solver. $B'gr$ is the angle input to the component solver as shown in figure 13–7.

The value of b is assumed to be equal to 100 yards and is built into the gearing of the inverse range input. Thus the component solver output is parallax based upon a 100-yard base as a standard base between a gun and its director. A set of change gears convert this value of parallax to the value required by the gun at which the parallax corrector is located. The change gears are located in the parallax corrector output shafting. These gears are ordinary gears which may be exchanged with ones whose ratio has been chosen to take care of the difference in base length compared to the 100-yard standard. For example, if the gun is located 50 yards away from the reference point, a 50/100 ratio is formed, and a 1:2 ratio set of gears is required.

The output, *Ph*, is combined in a differential with gun train response, which causes the gun to train through the angle *B′gr* plus *Ph* called *B′k*.

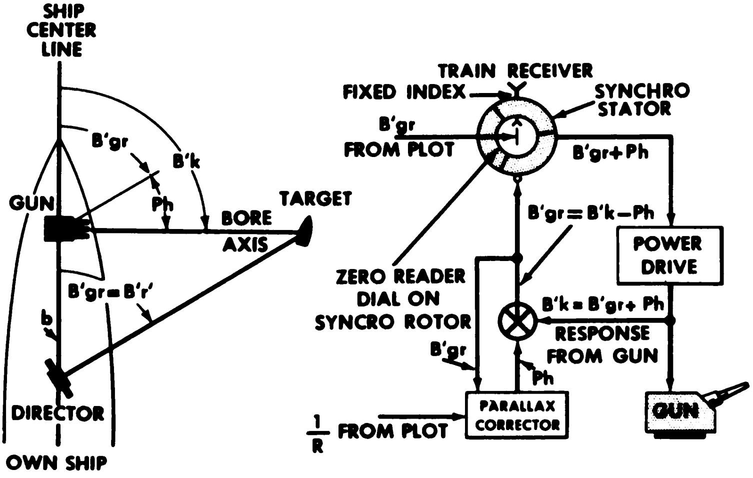


Figure 13–7.—Compensating for horizontal parallax in surface fire.

A schematic arrangement of a train receiver with facilities for correcting horizontal parallax is shown in figure 13–7 (right). A careful study of the figure will indicate that *Ph* simply corrects the *B′gr* input to the gun train power drive. It does this when the two quantities combine as they are fed into the response line leading to the synchro stator. *Ph* is then subtracted from the gun train response, *B'k*, in the differential. The differential output then positions the synchro stator through the correct response signal. Thus the gun automatically follows the *B'gr* signal corrected for parallax.

DIRECTOR PARALLAX

In figure 13–8, suppose the forward director is in control, and is transmitting *B'r'* to plot where *Ds* and *Dz* are added to make up *B'gr*. The guns, training in accordance with the *B'gr* order, are corrected for horizontal parallax to the forward director.

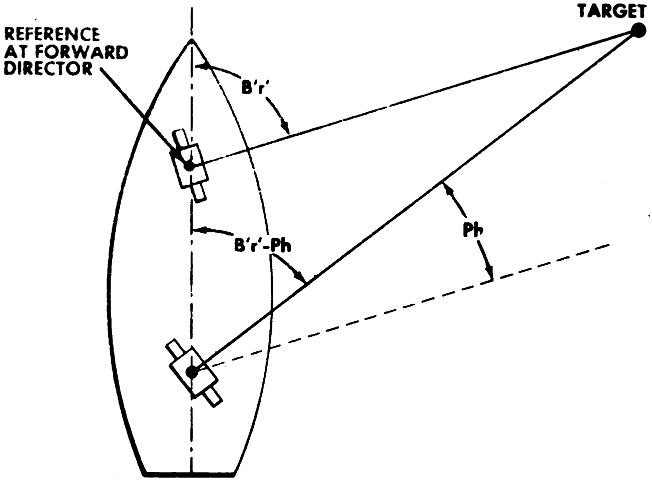


Figure 13–8.—Parallax between two directors.

But suppose the after director takes control. Now the train of this director is a smaller angle than train of the forward director. Thus, when the train of the after director is sent to plot, the gun order will be changed and the guns will move off the target. This happens because the guns are correcting for parallax with reference to the forward director but are receiving gun train order based on the after director.

To remedy this difficulty, a parallax corrector is installed in the after director which adds *Ph* to director train to drive the director transmitters. Thus, the after director does not transmit actual director train; instead, it transmits the value which director train would have if the forward director were tracking the target.

In some installations both directors have parallax correctors. Then each of them transmits to plot the value which director train would have if the director were located at some central REFERENCE POINT, as shown in figure 13–9. In other words, each director measures director train as if it were located at a common point.

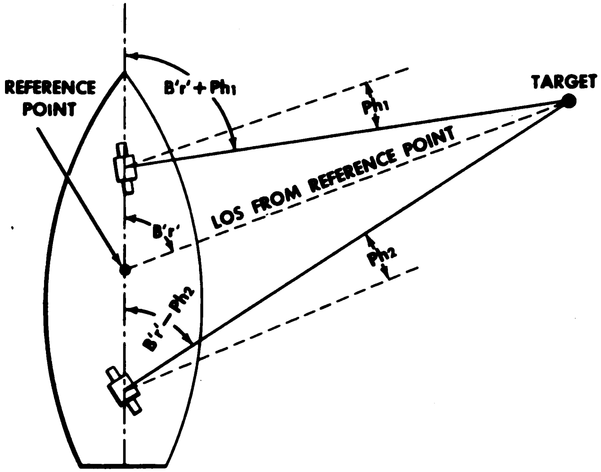


Figure 13–9.—Director horizontal parallax corrected to a central reference point.

When this is done, the horizontal base length set into each director parallax corrector is the distance the respective director is located from the reference point. From the foregoing it is evident that when all directors and guns are corrected for horizontal parallax with respect to some common reference point, any one director can control any gun or guns.

GUN ELEVATION ORDER

Gun elevation order, $E'g$, is obtained by adding the three quantities Vs, Vz, and L' as shown in figure 13–10: $E'g = Vs + Vz + L'$.

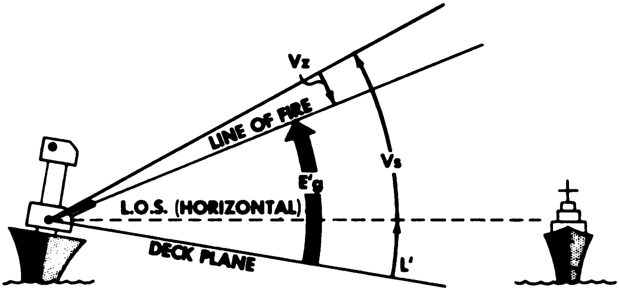


Figure 13–10.—Gun elevation order.

Actually, Vz is always a down or negative correction, so it is added algebraically to Vs. L' is transmitted directly from the stable vertical by shafting as indicated in figure 13–11.

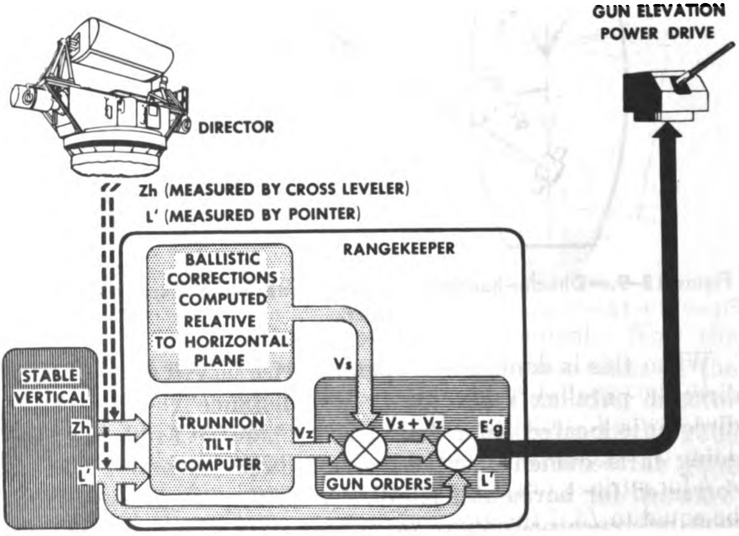

GUN ELEVATION POWER DRIVE
DIRECTOR
Zh (MEASURED BY CROSS LEVELER)
L' (MEASURED BY POINTER)
RANGEKEEPER
BALLISTIC CORRECTIONS COMPUTED RELATIVE TO HORIZONTAL PLANE
Vs
STABLE VERTICAL
Zh
L'
TRUNNION TILT COMPUTER
Vz
Vs + Vz
E'g
GUN ORDERS
L'

Figure 13-11.—How the rangekeeper manufactures $E'g$.

Vs contains all ballistic corrections that are computed in relation to the horizontal plane. But since *E′g* is measured from the deck plane, it is corrected for trunnion tilt by adding *Vz* to *Vs* in a differential. This output is then combined with *L′* in a second differential to make up the gun elevation order, *E′g*.

E′g is now transmitted by synchro transmitters to the gun where it is received by synchro receivers that control the gun elevation power drive. The power drive then elevates or depresses the gun in response to the *E′g* signal.

DIRECTOR ELEVATION AND VERTICAL PARALLAX

When the surface system is in full automatic operation, it is not necessary to use director elevation in the computation of the gun orders. Gun elevation order then is computed entirely by the rangekeeper and stable vertical. Present range, which comes from the director, is necessary in the computation of *Vs*, as *Vs* enters into the solution of *E′g*.

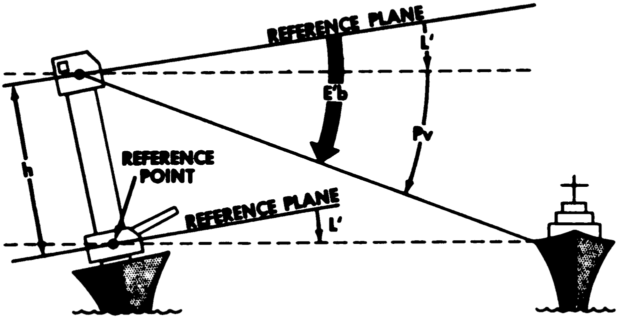


Figure 13–12.—Vertical parallax is taken into account when measuring *L′* at the director.

In the event of stable vertical failure, some other method of measuring *L′* must be available before *E′g* can be computed. This is accomplished by the director as it measures *E′b*. *E′b* for surface fire is essentially equal to *L′*; in fact, it would be equal to *L′* if the gun and director were always located the same height from the deck. But this is not the case because the director is invariably located above the gun in order to improve visibility.

Consequently, vertical parallax, *Pv*, must be considered. Vertical parallax is caused by the vertical distance *h* between the director and gun, as shown in figure 13–12. The value of *Pv* is roughly equal to the vertical distance *h* multiplied by parallax range $\frac{1}{R}$. This multiplication of inverse range by the constant *h* is performed in a gear ratio at the director.

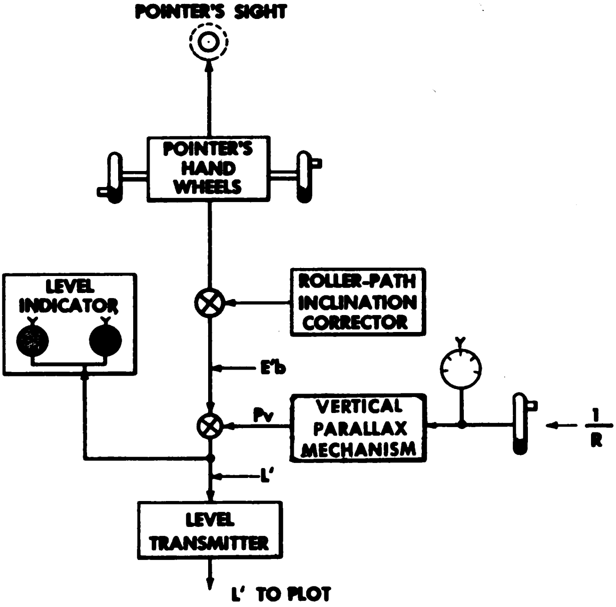


Figure 13–13.—Inverse range is cranked in at the director pointer's station.

A hand crank and dial at the director pointer's station drives inverse range through a set of change gears into a differential in the line from the pointer's hand wheels to the level synchro transmitters, as shown in figure 13–13. The dial is graduated so that it reads present range, but actually, INVERSE RANGE is the quantity that is set in. Then the elevation of the gun LOS, or level, becomes the quantity that is transmitted to the rangekeeper in plot.

REFERENCE PLANE

The elevation of all elements of a battery is measured from a standard REFERENCE PLANE. This plane is arbitrarily selected for each ship; it may be the plane of the director roller path, or the roller path of a gun. The reference plane is especially important in battery alignment.

The reference plane is necessary because no two elements in a battery have parallel roller paths. One element may tilt astern, another to port or to starboard. These roller paths deviate from each other by only a few minutes of tilt. But a few minutes may mean a miss at a range of several thousand yards, so a reference plane common to all battery elements is chosen and then all elements are corrected to this reference.

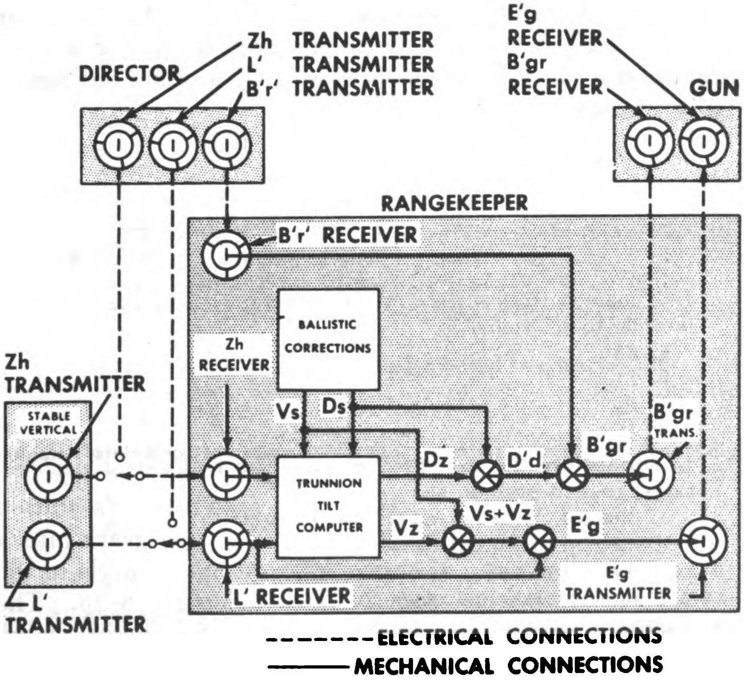


Figure 13–14.—Quantities that make up the gun elevation and train orders are transmitted and received by the synchros.

Each element in the battery has a roller path compensator—shown as the roller path inclination corrector in figure 13–13. The roller path compensator is adjusted for each battery element to correct all transmitted elevation angles to the reference plane.

SYNCHRO TRANSMISSION

All information that flows into the gun orders is transmitted and received electrically by synchro transmitters and receivers.

Figure 13–14 is a simplified diagram of a main battery fire-control system showing how quantities that help make up the gun orders are received by synchros from the director and stable vertical, and how the rangekeeper outputs and the gun train and elevation orders are transmitted by synchros. A thorough understanding of this setup will help you in troubleshooting in both the main battery and dual purpose fire-control systems because they are laid out essentially the same.

QUIZ

1. In a main battery surface system director elevation is measured in order to determine
   - a. *Zh*
   - b. *L'*
   - c. *Eg*
   - d. *E*
2. In surface fire the two director quantities required to establish target present position are
   - a. director elevation and the line of sight
   - b. director train and elevation
   - c. director elevation and range
   - d. director train and range
3. Ballistic corrections are always computed relative to what plane?
   - a. LOS
   - b. Deck
   - c. Vertical
   - d. Horizontal

4. Gun train order is equal to the sum of
   a. $B'gr$, Ds, and Dz
   b. Ds, Dz, and L'
   c. $B'r'$, Ds, and Dz
   d. Br, Ds, and Dz
5. Horizontal parallax varies with
   a. own ship speed
   b. target speed
   c. target angle
   d. range
6. The formula, $Ph=b/R$, is correct only when the target is
   a. directly abeam
   b. at a bearing of 45° relative
   c. dead ahead
   d. dead astern
7. In a surface fire-control system, the only quantity transmitted from the rangekeeper to the parallax corrector at the guns is
   a. b
   b. Ph
   c. $1/R$
   d. b/R
8. $B'gr$ is used when Ph is being computed at the
   a. rangekeeper
   b. stable vertical
   c. gun
   d. director
9. When two directors, separated by a certain horizontal base length, are corrected for horizontal parallax, their
   a. transmitted director train angles are equal
   b. train angles from the bow of the ship to their lines of sight are equal
   c. present range outputs will be corrected to a fixed point
   d. train angles will be equal only when the target is directly abeam
10. Director elevation minus vertical parallax, Pv, is substantially equal to
   a. E'
   b. E
   c. L'
   d. h/R
11. All guns are aligned in elevation to the
   a. reference plane
   b. reference point
   c. deck plane
   d. mean trunnion height

12. Inverse range is introduced into the vertical parallax computer by
    a. a hand crank
    b. synchros
    c shafting from the rangekeeper
    d. shafting from the stable vertical

13. The roller path compensator for a gun is located
    a. at the director
    b. at the gun
    c. in plot
    d. in the rangekeeper

CHAPTER 14

GENERATED RATES

All computations discussed earlier have been based on values which were cranked into the rangekeeper. We had to assume that those initial values were correct to solve the problem. For example, present range *R* was used in all computations, but a little reasoning will tell you that *R* changes as the target and own ship change their positions. *R* is not the only quantity that will change; range rate *dR* will also change as target angle *A* and relative target bearing *Br* change. The rangekeeper operator would have to CONTINUALLY crank in *R* manually in order to get a good solution. And to do that, he would have to be told what present range is from instant to instant.

However, the rangekeeper is designed to keep range by generating a quantity known as GENERATED PRESENT RANGE *cR* (*c* being the symbol for generated). In all rangekeeper calculations, *cR* takes the place of *R*, and it is computed with the help of an integrator. *cR* appears as a counter reading on the face of the rangekeeper. The rangekeeper operator simply watches the counter and compares generated and observed range and makes corrections to the initial setting of range whenever necessary. (See fig. 14–1.)

Let us first investigate what happens to range as the target moves before tackling the problem of generating *cR*.

The following quantities are known: range, and the course and speed of own ship. You estimate the target angle and speed. With these quantities it is possible to calculate what the range should be at any future time, and this calculated range can be compared with a measured value. If it turns out to be wrong, you know that your estimates of target motion were wrong.

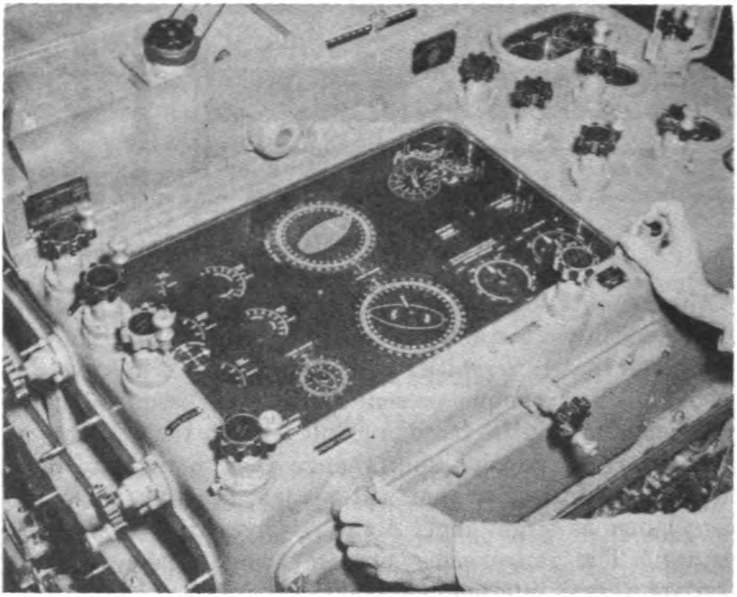


Figure 14-1.—Rangekeeper operator correcting range.

Suppose that in figure 14–2 own ship is at rest and the target ship is in position *B* moving at speed *S*. Its direction is at right angles to the LOS, that is, target angle is 90°. If you resolved *S* into components IN and ACROSS the LOS, the range component would be zero and deflection component would equal target speed *S*.

When the ship is in this position, the range is not changing at all. Target movement is changing the bearing of the target, but, for the moment, range is not changing. As the target moves a short distance along its course, target angle would begin to increase, the range component of *S* would be greater than zero (as in position *C*) and range would begin to increase. The speed with which range would change would depend upon the value of the range component of target movement. Thus, at position *A* in figure 14–2, target angle is less than 90°, the range component is tending to close the range, and the range is decreasing at a speed equal to the target range component *Yt*. At position *B*,

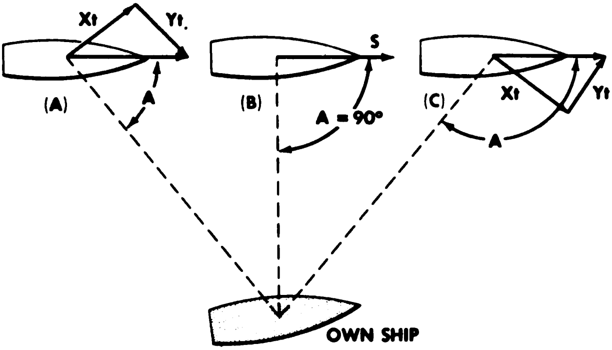


Figure 14-2.—Effect of target movement on range.

where *A* equals 90°, there is no range component and the range is not changing. A little later, at position *C*, the target angle is greater than 90°, *Yt* points outward, and the range is increasing.

The same reasoning applies to the movement of own ship. You can see in figure 14-3 that the rate at which range changes will depend on *Yt* and *Yo*. The sum of *Yt* and *Yo*

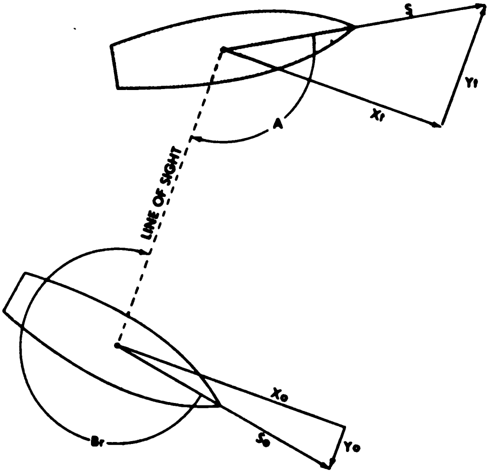


Figure 14-3.—How range rate is obtained.

is equal to range rate *dR* (where *d* is a sign meaning "rate of change of"), or $dR = Yt + Yo$.

Remember that *dR* is an instantaneous value and is true only for a given instant because *dR* changes as target angle and relative target bearing change.

However, as long as *Br* and *A* are correct, even though they are always changing, the own ship and target component solvers will always furnish the correct value of *dR*, and *dR* will always indicate the speed with which range is changing at any instant. Therefore, in order to get the total change in range over a given period of time, all you have to do is INTEGRATE *dR*. That is, you multiply *dR* by time as time elapses and the result will be the total change in range in yards at the end of any given period of time. The integrator performs this function continuously.

RANGE INTEGRATOR

Let us examine the process of integration a little closer and assume that *dR* is equal to 20 yards/second. After 10 seconds the total change in range would be 200 yards, that is, change in range equals *dR* times time, or $20 \times 10 = 200$ yards. But this is not a typical case as *dR* is always changing.

A better example would be to take several values of *dR* over a given period of time. Say that for the first 5 seconds *dR* is 20 yards/second, for the second 5 seconds *dR* is 25 yards/second, and for a third 5 seconds *dR* is 30 yards/second. Then at the end of 15 seconds the total change in range would be the sum of the products of each of the three *dR's* multiplied by the time over which each persists, or 375 yards:

$$
\begin{array}{l}
dR1 \times T1 = 20 \times 5 = 100 \text{ yds.} \\
dR2 \times T2 = 25 \times 5 = 125 \text{ yds.} \\
dR3 \times T3 = 30 \times 5 = 150 \text{ yds.} \\
\hline
\text{Total change in range} = 375 \text{ yds.}
\end{array}
$$

This is essentially the process of integration.

Now *dR* does not change in steps because neither target angle nor relative target bearing changes in steps; instead, *dR* changes smoothly. At one moment it may be gradually decreasing to zero and at another it may be increasing, but the change will always be like a smooth curve on a graph.

Given the changing values of *dR*, the range integrator is free to do its work. Using an infinite number of values of *dR*, the range integrator multiplies each value by the time over which it persists and continuously accumulates the products of these multiplications. The result is known as INCREMENTS OF RANGE, or ΔcR. The Greek letter delta, Δ, means either CHANGES IN or INCREMENTS OF. Therefore, ΔcR will always give you the total change of range at the end of any given period of time.

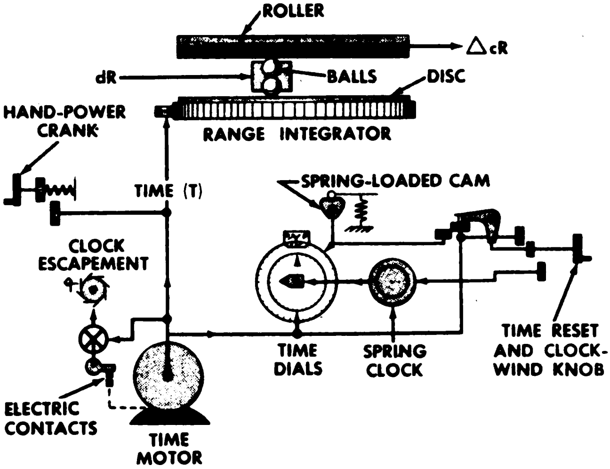


Figure 14–4.—Range rate integrator showing how time is introduced.

The range integrator disk in figure 14–4 is driven at a constant speed by an electric motor known as the TIME MOTOR. The carriage is positioned by a rack and pinion, driven by the *dR* shaft. When the range rate is zero, the balls of the carriage are directly over the center of the disk and the disk rotation has no effect. However, if the range rate input has a definite value, the carriage and balls will be moved off toward one side of the rotating disk. When this occurs, the motion of the disk will be transferred by the balls to the roller and the roller will then revolve at a speed which depends on the displacement of the carriage from zero, and also upon the value of *dR*. The amount of roller rotation represents increments of range ΔcR.

The accuracy of ΔcR depends upon *dR* and TIME inputs. *dR* depends on how accurate the settings are at the own ship and target component solvers. Time is equally important and therefore is introduced by a special mechanism shown in figure 14–4.

The time motor is a split-phase induction motor with a special regulator to make it run at an exact constant speed. The operation is as follows: One side of the differential is driven by the time motor which always tries to run too fast. The other side of the differential is connected to an escapement movement like that in a clock. The important thing about the escapement is that it can be turned freely at a certain speed, but resists being turned any faster. When the time motor is running at the escapement speed, it drives out of the differential through the escapement But if the motor turns faster, the escapement resists and the excess motion backs up into the differential spider. This opens the electric contacts shown in figure 14–4, cutting off the power to the motor until it slows down to the proper speed. This happens very quickly from instant to instant and the rotation of the motor shaft appears perfectly constant.

The arrangement of the time dial in figure 14–4 is a little complicated. The time motor drives the inner dial at one turn per minute and the outer dial at one turn per hour. The pointer is driven at one turn per minute by the spring clock. This provides a check on the accuracy of the time motor speed. The inner dial and the pointer should move together when the motor is running at the correct speed.

If the time motor should fail, a hand power crank can be pushed in and used to drive time into the rangekeeper manually. It should be turned at a rate which makes the minute dial move with the pointer.

When the time knob is pulled out from its neutral position, it is used to wind the spring clock, which must be done weekly. When the knob is pushed in, it disconnects the outer dial from the time motor and a spring-loaded heart cam snaps the outer dial to zero. The knob is also geared to the time line so that the inner dial can be set at any desired point.

Generated Present Range

With ΔcR being constantly generated, generated present range cR may be found by adding ΔcR to initial range jR. jR is measured by the rangefinder or radar and the addition is made in a differential as shown in figure 14–5: $cR = jR - \Delta cR$.

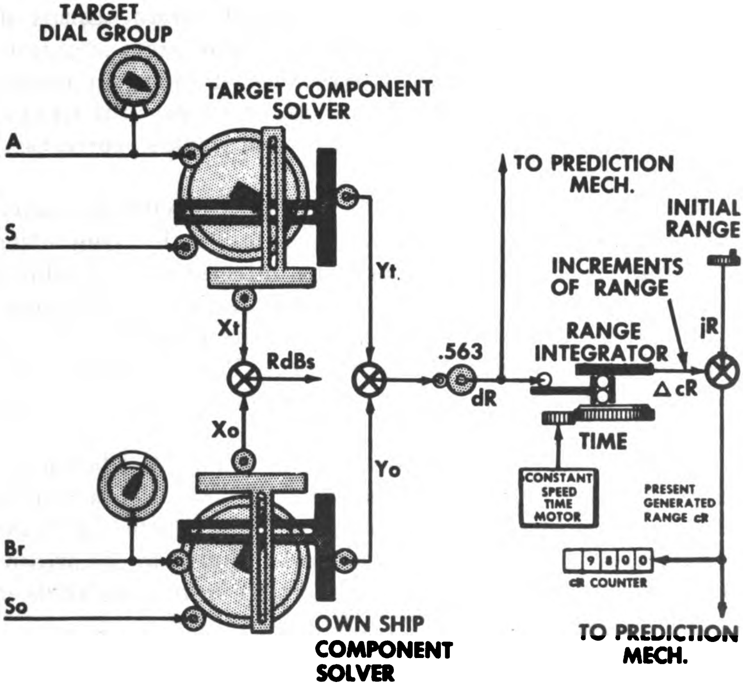


Figure 14–5.—Generated present range cR.

Generated range is indicated on the counter and by observing the cR counter the operator may make a comparison of the generated and observed values of present range. If they do not agree, the operator corrects the inputs of target angle and target speed and also the initial setting of range, jR, if necessary, as it could be in error. But it is easy to tell whether it is the target inputs or jR which is in error. If cR CREEPS away from the observed range, then the target inputs are in error; if cR is always incorrect by a constant amount, jR is in error.

Generated Bearing

The rangekeeper is designed to generate true target bearing from the initial settings of own ship and target motion and from target bearing. If the target is momentarily obscured, the rangekeeper will maintain a correct target bearing in the absence of director train as long as the target maintains its same course and speed. Whenever the director trainer is on target, the rangekeeper operator compares the GENERATED and OBSERVED QUANTITIES and makes corrections when necessary.

Generated target bearing cB is generated with the assistance of two integrators. cB is obtained by computing INCREMENTS OF BEARING, ΔcB, by integration and adding them to INITIAL BEARING jB. ΔcB indicates the TOTAL CHANGE in true bearing at the end of any period of time; at any instant ΔcB plus jB will give cB. Then if you subtract Co from cB, you will get GENERATED RELATIVE TARGET BEARING, cBr.

Linear deflection rate, $RdBs$, indicates how fast bearing is changing and is the key to solving for ΔcB. To arrive at the formula for ΔcB you must multiply $RdBs$ by time. This gives the linear distance in yards tangent to the present range circle. But you want this change in bearing angle in minutes, so you divide by $\frac{cR}{1,000}$, thus changing the linear distance to mils. Then to get minutes you multiply by 3.43. To state this mathematically, you have

$$\Delta cB = \frac{RdBs}{cR/1,000} \times T \text{ mils} = 1,000 \times RdBs \times \frac{T}{cR} \text{ mils.}$$

Or, by multiplying by 3.43 to convert mils to minutes, you have

$$\Delta cB = 3.43 \times 1{,}000 \times RdBs \times \frac{T}{cR} \text{ minutes}$$

which is

$$\Delta cB = K \times RdBs \times \frac{T}{cR} \text{ minutes}$$

where K is equal to 3.43 times 1,000, or 3,430.

A sample problem will show you how the formula works. Suppose that *RdBs* is equal to 20 yards/second, the increment of time necessary to solve for range prediction is 10 seconds, and the generated present range is 10,000 yards. Solving for the bearing increments at the end of 10 seconds:

$$\Delta cB = 3{,}430 \times 20 \times \frac{10}{10{,}000} = 69 \text{ minutes (approx.).}$$

The quantity *RdBs*, just as with *dR*, is constantly changing because the values of target angle and relative target bearing change. The integrator takes the changing values of *RdBs* and multiplies them by the time over which each persists and continuously adds the products. These products give ΔcB, which represent the total change in bearing at the end of any time interval.

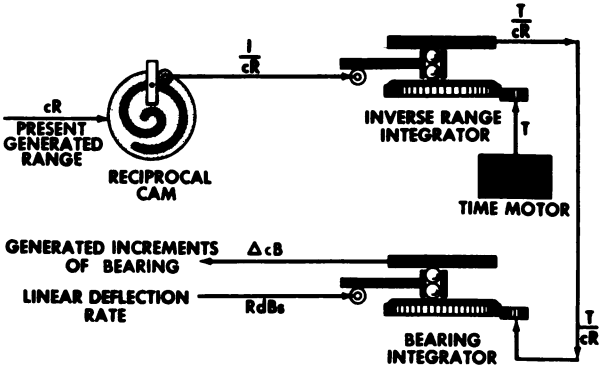


Figure 14-6.—Generating increments of bearing.

The mechanical units which solve the formula for ΔcB are shown in figure 14–6. Present range cR, generated from the range-generation mechanism previously described, drives into a reciprocal cam to give $\frac{1}{cR}$. The same time motor that drives the range integrator also drives the inverse range integrator. The output of the inverse range integrator drives the disk of the bearing integrator and the carriage is positioned by $RdBs$. The roller of the bearing integrator will now turn at a rate proportional to the product of $RdBs$ and $\frac{T}{cR}$. The output of the roller is ΔcB.

INCREMENTS OF DIRECTOR TRAIN

Increments of bearing have several uses, one of the most important being the calculation of increments of director train, $\Delta cB'r'$, which is supplied to the director. In main battery directors, $\Delta cB'r'$ is received by synchro for the pur-

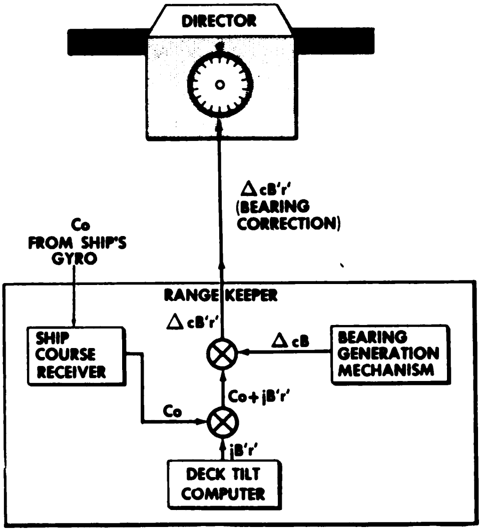


Figure 14–7.—Increments of director train are made up in the rangekeeper and transmitted to the director.

pose of INDICATING ONLY. Therefore, if the target is momentarily obscured, the director trainer can match dial pointers by turning his handwheel and $B'r'$ transmitted to the rangekeeper will be correct as long as ΔcB is correct, or as long as the target maintains the same course and speed.

Figure 14–7 shows that $\Delta cB'r'$ is made up in the rangekeeper by adding ΔcB, Co, and $jB'r'$. Co comes from the ship's gyro by synchro and $jB'r'$ is made up in the deck tilt computer from $B'r'$, L', and Zh.

COMPARING GENERATED AND OBSERVED RELATIVE TARGET BEARING

Another important feature of the bearing generation mechanism is that it affords a means of continuously and accurately correcting target angle and relative target bearing.

However, before we can be assured that ΔcB is correct, we must COMPARE the observed quantities sent down from the director with the quantities generated by the rangekeeper.

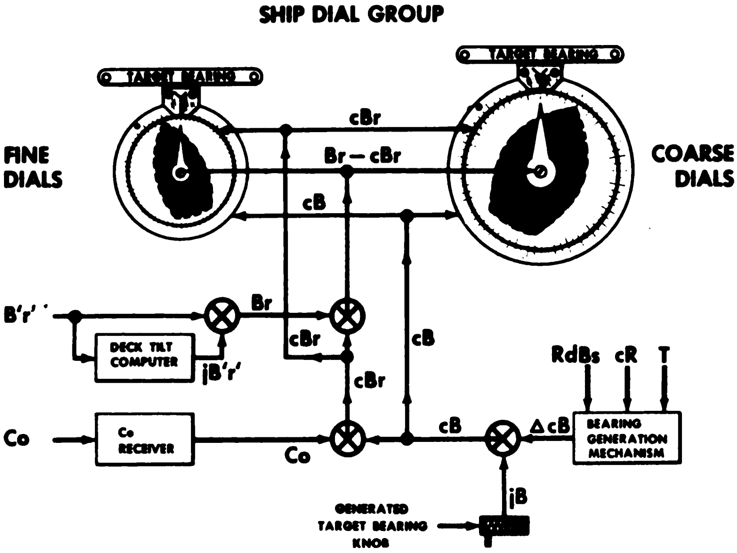


Figure 14–8.—Comparing generated and observed quantities at the dial group.

This comparison is made at the dials mounted in the rangekeeper face. The quantities compared are relative target bearing *Br*, derived from *B'r'*, and generated relative target bearing *cBr*. To calculate *cBr* it is necessary to find generated true target bearing *cB*, which is done in a differential as shown in figure 14–8. *cB* is equal to the sum of ΔcB and *jB* (initial bearing). The quantity *cB* can be read in degrees and minutes at the outer or ring dials.

cB is added to *Co* in another differential to make up generated relative target bearing *cBr*. *cBr* is then subtracted from *Br* in a differential to position the POINTERS of the dial group. These pointers, read against the ship dial, indicate observed relative target bearing *Br*. The pointers are positioned according to the DIFFERENCE between the generated and observed relative target bearing, and will always point to the target bearing indexes if generated target bearing is the SAME as the observed.

Refer to figure 14–8 and look at the coarse and fine dial groups. The coarse dials are calibrated up to 360° and supply a rough reading. At the left of the coarse ship dial group are the fine dials, consisting of fine ship dial, a compass ring and an observed relative target bearing pointer. The fine dial group rotates with and corresponds to the elements of the coarse dial group, except that one revolution of the fine dial group, represents 10° instead of 360°.

The generated target bearing knob shown in figure 14–8 is located at the front of the rangekeeper and is used to make initial corrective settings to generated target bearing. When the rangekeeper is in operation with normal inputs, the knob is used initially to bring the observed relative target bearing pointers of the coarse and fine ship dial groups into line with their respective target bearing indexes.

CORRECTING TARGET ANGLE AND RELATIVE TARGET BEARING

The quantity *cBr* is used in all rangekeeper computation and is correct when the generated and observed quantities are matched. Figure 14–9 shows how *cBr* feeds into the

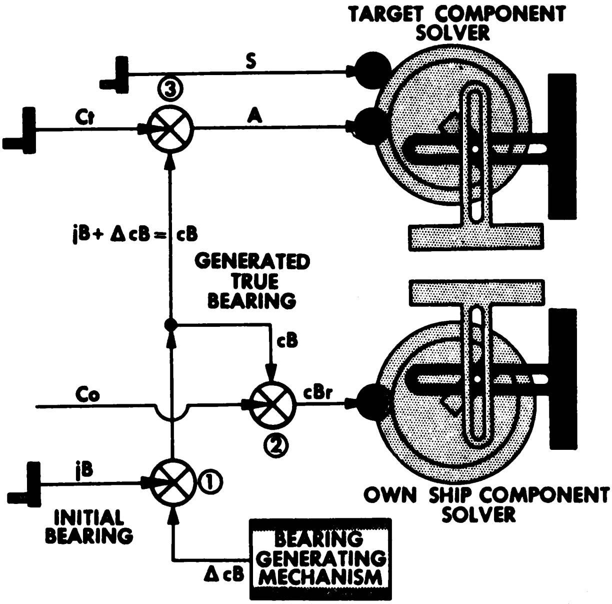


Figure 14–9.—How increments of bearing drive the own ship and target component solvers.

own ship component solver to enter into the calculation of the X and Y components of own ship motion.

Referring to that figure you will see that the increments of bearing drive through differentials 1 and 2 to correct *cBr* continuously, and into differential 3 to change target angle A. Figure 14–10 illustrates how ΔcB can correct target angle.

Refer to figure 14–10 and assume that own ship and target are at points 1–1 and are maintaining their courses and that the initial true bearing *jB* has been cranked in as shown. The angles *Co*, *cBr*, and A are also illustrated at point 1–1.

When both ship and target reach point 2–2, both *cBr* and A have changed to *cBr*1 and $A1$. At point 2–2 lines from both own ship and target have been drawn parallel to the original LOS between points 1–1. By referring to the line drawn from own ship parallel to the original LOS, it can be seen that angle $\Delta cB1$ is the angle between the parallel line and the new LOS 2–2. Likewise, an increment of target angle, $\Delta A1$, between the parallel line from the target and the new LOS 2–2, is drawn in.

Since the lines from own ship and target are parallel to the original LOS, they are also parallel to one another. Therefore, the new line of sight between 2–2 is a line which intersects two parallel lines. Now, when two parallel lines are intersected by a straight line, the alternate interior angles are equal and so $\Delta cB1$ is equal to $\Delta A1$, that is, increments of target angle are equal to increments of bearing.

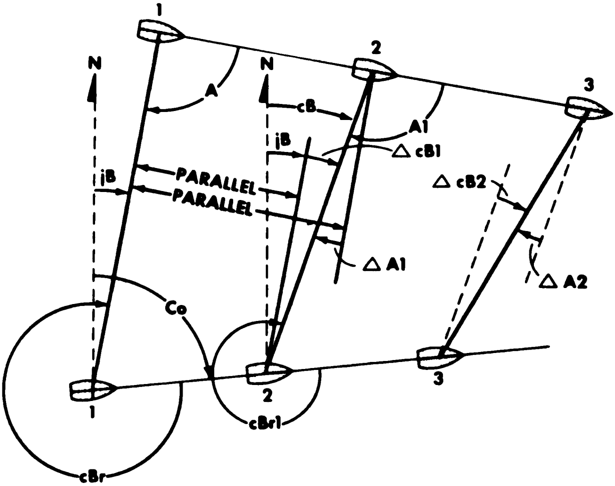


Figure 14–10.—How increments of bearing equal increments of target angle.

This explains why increments of bearing drive the angle gear of the target component solver in figure 14–9. Thus, once target angle is correct it will remain correct as long as the target holds the same course and speed.

Upon further inspection of the figure at point 2–2, it will be seen that *cB* equals *jB* plus *cB*1, the first total increment.

TRACKING SECTION

The function of the tracking section of a rangekeeper is to establish the relative motion rates, *dR* and *RdBs*, so that the change in target position during the time of flight of the projectile can be predicted. The tracking section contains the mechanisms for setting up the problem, for computing the relative motion rates, and for comparing the observed and generated quantities.

Figure 14–11 shows the generating mechanism of the most widely used surface rangekeeper. It is simply everything you have studied so far in this chapter combined in one schematic diagram. This schematic shows how the generated quantities are made up and to what sections of the rangekeeper they are sent.

The main steps in the computation are shown by the heavy lines in figure 14–11. The lighter lines indicate such things as connections to dials and auxiliary equipment.

The computations of generated range *cR* and generated true bearing *cB* start with the own ship and target component solvers. Estimated target speed is set directly into the target component solver by a hand knob. Target angle, the other input, is obtained in differential *D*–5 combining target course with the continuously changing value of generated true bearing. *Ct* is set by bringing the target angle dial to the correct value; then *Ct* stays fixed and the changes in *cB* keep *A* at the correct value. *D*–2 is a compensating differential for the target component solver.

Inputs to the own ship component solver are normally automatic. *So* is set in by a synchro receiver and a servo follow-up, and *Co* by a pair of synchros and a servo follow-up. Both follow-ups are of the magnetic drag type that average out small fluctuations in the synchro signals. *Co* is driven into *D*–4 by its follow-up, where it combines with *cB* to give *cBr*, the input to the own ship component solver. *D*–1 is a compensating differential for the own ship component solver.

The *So* and *Co* hand knobs are disengaged in their OUT POSITION. When they are at the IN POSITION, they de-energize the follow-ups and you can introduce the quantities by hand.

Referring to figure 14–11, you will see that generated relative bearing also drives into *D*–13, where it is subtracted from observed relative target bearing ($Br = B'r + jB'r$). The difference (error in generating bearing) drives the pointers on the ship dial group. These pointers are zero-readers and point at the fixed indexes of the own ship dial group when the generated value of relative target bearing agrees with the observed.

The *Yo* and *Yt* outputs of the component solvers combine in *D*–8 to form range rate *dR*. This quantity goes to the prediction section, shows up on a dial, and also positions the carriage of the range integrator. The integrator output ΔcR feeds into *D*–16. The other input to *D*–16 is the initial value of range, *jR*, which is set by a hand knob. When tracking starts, present range is set in on the counter (bottom of figure 14–11) by the hand knob to agree with the rangefinder or radar readings that show up on the graphic plotter or are received by phone.

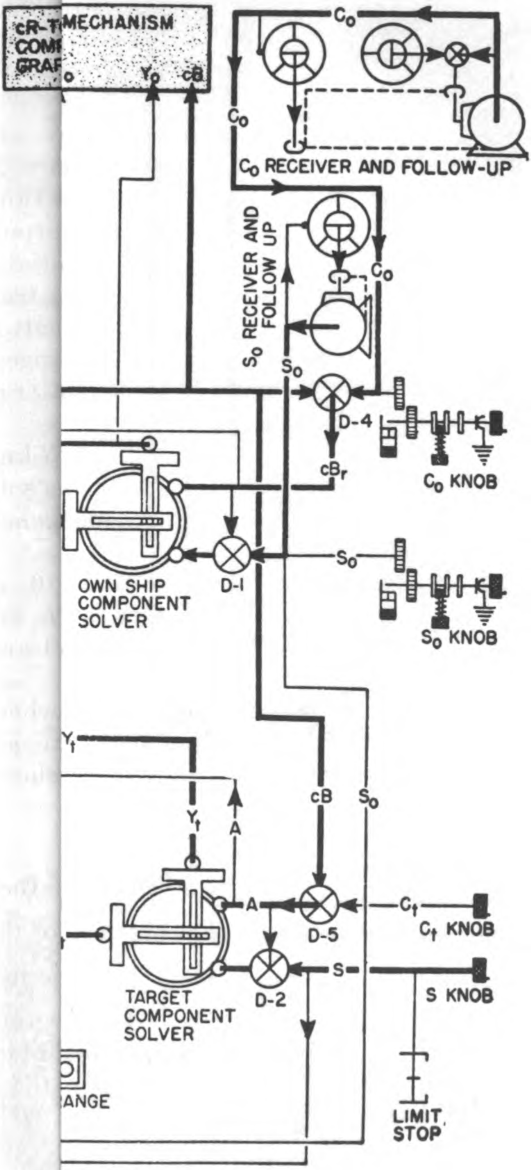
As tracking progresses, *cR* is adjusted with the *jR* knob to make it agree with observed present range. When a solution is achieved the two values, observed range and generated range, will stay in agreement.

Generated present range *cR* is the output of *D*–16, which shows up on the present range counter, operates the inverse range cam, and feeds into the ballistic section and graphic plotter.

Linear deflection rate *RdBs* is obtained in *D*–10 where the *Xo* and *Xt* outputs of the component solvers are added. *RdBs* then feeds into the prediction mechanism, shows up at the dials, and positions the carriage of the bearing integrator.

The disk of the bearing integrator is driven by $\frac{T}{cR}$, the output of the inverse range integrator. The carriage of the inverse range integrator is positioned by $\frac{1}{cR}$ from the inverse range cam. Thus the output of the bearing integrator is ΔcB, rather than increments of linear deflection in yards. The division by range has been accomplished in the integrator. In differential *D*–7 ΔcB is combined with *jB* from the generated bearing hand knob to form *cB*.

The *jB* knob is adjusted from time to time as tracking



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starts to keep the relative bearing zero-reader pointers matched up. When a correct solution is reached, the zero-readers will stay matched without any further movement of the *jB* knob.

Generated true bearing drives into the prediction mechanism. It also feeds back to the component solvers, where it maintains inputs *cBr* and *A* at the correct values, thus completing the regenerative cycle.

RATE CONTROL

The tracking system of a rangekeeper offers you a check on the accuracy of your original estimates of TARGET SPEED and TARGET ANGLE, the only unknown quantities.

With the rangekeeper mechanism you can check your accuracy before you fire. Every once in awhile you can check the generated quantities against the observed quantities and, if the generated values continue to run along with the observed values, you know that your estimates were correct. But should the values disagree, you know that the estimates of target angle or speed, or both, must be wrong.

With the value of *A* at 0°, 90°, 180°, or 270°, the problem is simple there being only one target motion quantity to consider in correcting either range rate or deflection rate. However, when the target lies at intermediate values of *A*, both *A* and *S* may be involved, and the relative amount to correct each must be found.

Course and Speed Change Indicators

To the inexperienced operator, the course and speed change indicator can be of aid in determining the necessary corrections to the original estimates of target speed and target angle. When disagreement between the observed and generated quantities exists, the indicators will show whether changes in target course or in target speed will be the more effective in correcting the error and also the direction in which to turn the respective handcrank.

Figure 14–12 shows the course and speed change indicators. Top and bottom windows of each indicator are the range windows. Right and left windows of each indicator are the bearing windows. The nature of the error determines which windows should be referred to for information. For instance, when the sign of the range rate error is found to be negative, the top window of each indicator is referred to.

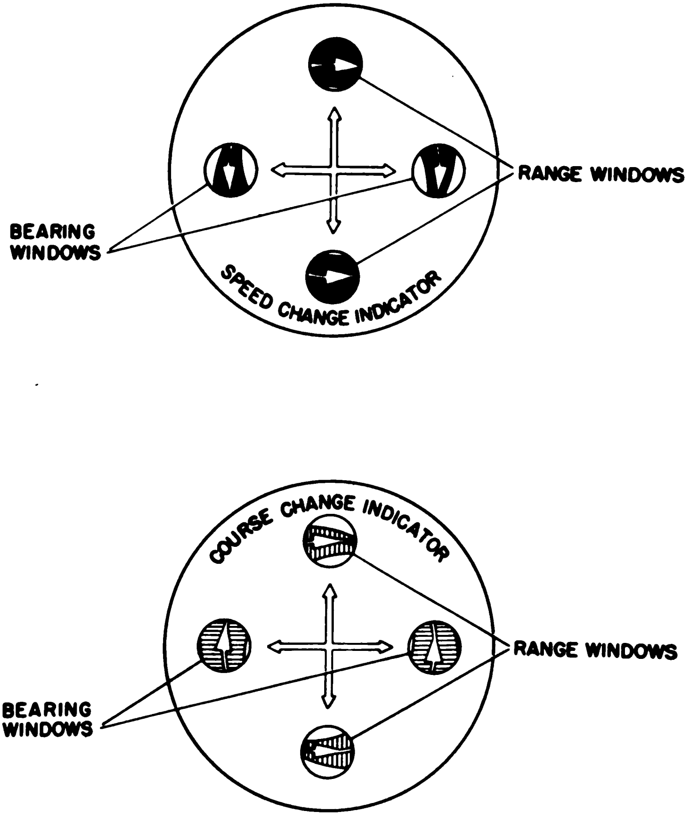


Figure 14-12.—Speed and course change indicators.

When the sign of the range rate error is positive, the bottom window of each indicator is referred to. When the observed pointers are rotating clockwise, indicating a negative rate error, the right window of each indicator is referred to.

Since incorrect estimates of target motion usually cause generated range and relative target bearing to be in error, reference is made to both a range and a bearing window of each indicator.

When the appropriate windows have been determined, a comparison of the width of the color bands appearing in the windows will indicate which quantity is the more effective in changing the rate. For instance, assume the condition to be such that the top and left windows of each indicator are being referred to. If the band appearing in the top window of the speed change indicator is wider than the band appearing in the top window of the course change indicator, as in figure 14–12, a change in target speed will be more effective for changing the range rate than a change in target course. Likewise, if the band appearing in the left window of the course change indicator is wider than the band in the left window of the speed change indicator, a change in target course will be more effective for changing the deflection rate than a change in target speed.

The arrow appearing with the color band indicates the direction in which to turn the corresponding, similarly-colored handcrank. For instance, in the above example if the arrow in the top window of the speed change indicator is pointing clockwise, turn the target speed handcrank clockwise.

When *Ct* or *S* is changed to correct one of the rates, the effect of this change on the other rate can also be determined from the indicators. Assume that a range rate correction is to be made by turning the target speed handcrank in the direction indicated by the arrow in the top window of the speed change indicator, and that the left windows are being referred to for the bearing error. Since the arrows in the top and left speed change indicator windows point in opposite directions, turning the handcrank to correct the range rate error will cause an increase in the deflection rate error. In this case, both the target speed and target course handcranks must be rotated to correct the errors.

If the arrows in the top and left windows of the speed change indicator point in the same direction, turning the target speed handcrank to correct the range rate will also make a corrective setting for the deflection rate.

Example of Rate Control

In order to illustrate the principles of rate controlling, the rate process in an average fire-control problem will be described.

Figure 14–13 is a diagram of conditions shortly after the start of tracking, just as the first corrections are about to be

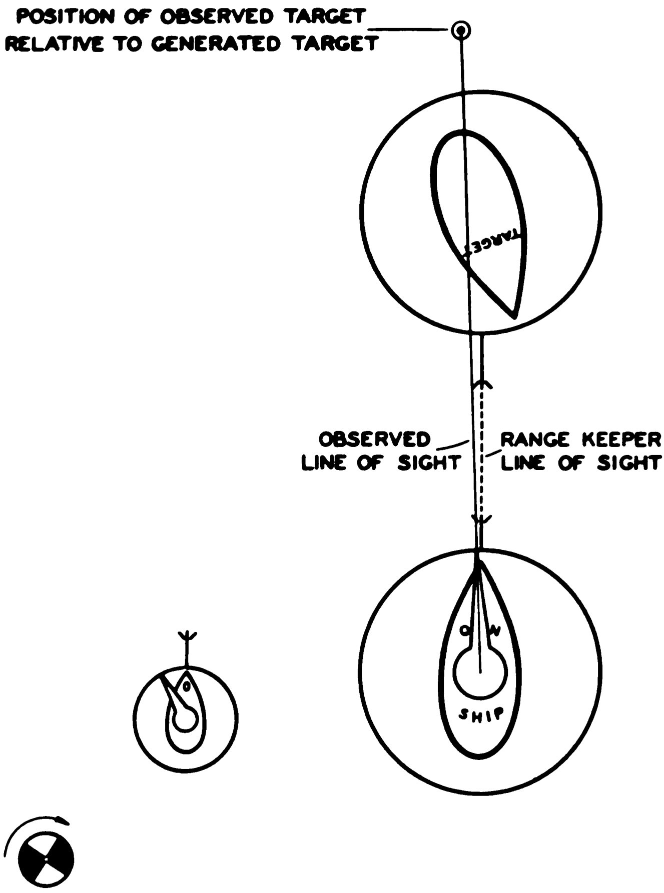

POSITION OF OBSERVED TARGET RELATIVE TO GENERATED TARGET
TARGET
OBSERVED LINE OF SIGHT
RANGE KEEPER LINE OF SIGHT
O
W
SHIP
O

Figure 14–13.—Indicator conditions for rate control example.

made. The target dial shows the generated target to be moving in and to the right. The range solution indicator is rotating clockwise. This indicates a minus error in the negative range rate, causing generated range to decrease too rapidly. Also, the observed pointers are rotating slowly counterclockwise, indicating that a plus error in the positive deflection rate is causing the generated target to move rightward more rapidly than the observed target. The total effect of the range and deflection errors places the observed target to the left and beyond the generated target in line with the coarse observed pointer.

Since the range error appears to be greater than the bearing error, range rate will be dealt with first. As the target is moving in and more nearly along the line of sight than at right angles to it, target speed is selected for the first correction and is reduced to make range rate less negative. As it is noted that this correction also improves deflection rate, it is carried to the point where the range solution indicator is almost stationary. However, the observed bearing pointers are still rotating counterclockwise, indicating a considerable error, so they are realigned with the fixed indexes by means of the generated bearing handcrank and a need for correction for deflection rate is deduced from the present conditions.

The target motion is still more nearly along the line of sight, so changing *A* will be more effective than changing *S* in controlling the deflection rate. The target is therefore adjusted to head more in the direction toward which the observed pointers point; that is, *A* is decreased, making deflection rate less positive. This correction is cut short of fully stopping the observed pointers as it has caused the range solution indicator to resume its original clockwise rotation. The observed pointers are again reset at the fixed indexes. Although both rates are now greatly improved, the indicators are still rotating in the original direction indicating conditions similar to those existing at the start of tracking. In view of this, the *S* correction is repeated; this time it is carried to the point where the range solution indicator is fully stopped. After resetting the observed pointers, it can be seen that they have reversed and are now rotating very slowly in the clockwise direction, thus indicating that *A* must have been overcorrected slightly. Therefore *A* is increased enough to cause the pointers to remain stationary, thus making the solution complete.

QUIZ

1. Generated present range is equal to
   a. $jR + \Delta cR$
   b. $jR + cR$
   c. $jR + cR + R$
   d. $dR + \Delta cR$
2. *dR* represents
   a. range rate prediction
   b. increments of range
   c. time rate of change of present range
   d. basic range prediction rate
3. When the generated present range does not match observed range, which of the following inputs are INCORRECT?
   a. *R* and *S*
   b. *S* and *So*
   c. *A* and *S*
   d. *B* and *So*
4. When target angle is 90°, linear range rate is
   a. maximum
   b. increasing
   c. decreasing
   d. zero
5. If own ship is motionless, what is the target angle when *cR* equals *S*?
   a. 0°
   b. 30°
   c. 60°
   d. 90°
6. If own ship is motionless, what is the angle between *Ct* and the LOS when *Yt* equals *S*?
   a. 0°
   b. 30°
   c. 60°
   d. 90°

7. Normally, how does the range integrator calculate dR?
   a. In infrequent steps
   b. In frequent steps
   c. Constantly and smoothly
   d. Infrequently but smoothly
8. When the range rate is zero, the carriage of the range integrator is
   a. rotating with the disk
   b. rotating opposite to the disk
   c. at the circumference of the disk
   d. at the center of the disk
9. What is the purpose of the pointer and inner dial of the spring clock mechanism of the time motor?
   a. To regulate the contacts
   b. To check the accuracy of the time motor speed
   c. To rotate the integrator disk
   d. To permit time dial resets
10. To wind the spring clock the
    a. time reset knob must be pushed in
    b. time reset knob must be pulled out
    c. hand power knob must be pushed in
    d. hand power knob must be pulled out
11. When $\triangle cB$ is added to the initial true bearing setting you get
    a. $cB'r$
    b. cBr
    c. jB
    d. cB
12. When own ship's course is subtracted from generated true target bearing you get
    a. Br
    b. jB
    c. cBr
    d. $jB'r'$
13. What is the bearing increments, in minutes, at the end of 20 seconds if the generated present range is 10,000 and the $RdBs$ is 10 yards/second?
    a. 39
    b. 43
    c. 69
    d. 1,000
14. Which of the following formulas give the generated relative target bearing?
    a. $cB=cB-Co$
    b. $cBr=cB-Co$
    c. $cBr=cB-jB$
    d. $B'r'=cB-Co$

15. The pointers of the target group dials on the rangekeeper indicate the difference between
    - a. ΔcB and $\Delta cB'r$
    - b. Br and $\Delta cB'r'$
    - c. jBr and Co
    - d. Br and cBr
16. Which of the following equations explains why increments of bearing drive the angle gear of the target component solver?
    - a. $A=B$
    - b. $cB=jB$
    - c. $\Delta cB=\Delta A$
    - d. $cBr=\Delta cB$
17. Increments of director train are equal to
    - a. $cB+cBr+Co$
    - b. $\Delta cB+Br+jBr$
    - c. $\Delta cB+jB'r'$
    - d. $\Delta cB+Co+jB'r'$
18. If generated relative target bearing creeps away from the solution, it is an indication that
    - a. target angle or target speed is in error
    - b. initial bearing setting is in error
    - c. either initial bearing or target angle is in error
    - d. either initial bearing setting or target speed is in error
19. Which of the following values is adjusted when making rate control corrections to the rangekeeper?
    - a. S
    - b. Co
    - c. Br
    - d. Zh
20. To change mils to minutes you multiply by
    - a. 100
    - b. 1,000
    - c. 3.43
    - d. 0.505

CHAPTER 15

RANGEFINDERS

In general, the term range is the distance to the target, and its measurement is the first step in the solution of a fire-control problem. Eye estimates of target distances were the earliest form of range measurement, and are still used to some extent. The ability to estimate distance by eye with some degree of accuracy is a valuable asset.

Among the instruments used to measure range for fire-control purposes is the rangefinder. In general, it consists essentially of a system of optical units assembled in a long, cylindrical tube. The tube is supported by a mount which permits training the rangefinder on the target. Early forms of mounts were little more than simple tripods, but modern rangefinders are generally supported on a mount, which is a part of the turret or director structure, leaving only the protruding ends of the rangefinder exposed.

TRIANGULATION

Figure 15–1 illustrates the principle of triangulation. If you are at point *A* and you want to know the distance to point *P*, you measure off any handy distance *AB* at right angles to *AP*. At point *B* you measure the angle θ between *BP* and the line *BC*, which is parallel to *AP*.

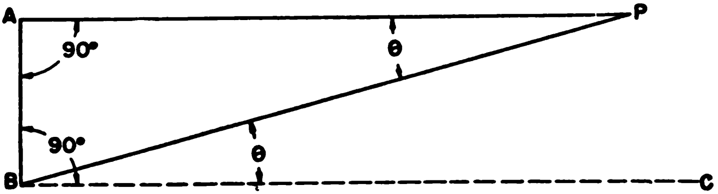


Figure 15–1.—Measuring distance by triangulation.

Figure 15–1 shows that angle APB will equal θ. Then you have—$\tan \theta = \frac{AB}{AP}$.

In a rangefinder the distance AB is called the BASE and is written B. It is the distance between the end reflectors of the instrument. AP is the range R. The triangulation formula for rangefinders can be written as

$$\tan \theta = \frac{B}{R}.$$

The small angle θ is called the PARALLACTIC ANGLE which is measured by the rangefinder.

Whether he realizes it or not, every man with two eyes has a built-in rangefinder of a sort. The brain has learned to sense distance by the angle each of your eyes is turned in to bear upon an object; but your eyes are spaced close together, and therefore you can judge only relatively short distances accurately. The stereoscopic rangefinder is a device to improve the performance of your own built-in rangefinder by increasing the distance between your eyes; this magnifies the parallactic angle.

SPREADING THE EYES

This is how you can "spread your eyes apart" with a rangefinder. A penta (5-sided) prism will turn a ray of light exactly 90°. Suppose you took a stiff metal bar, 15 feet long, and mounted a penta prism at each end. Turn the

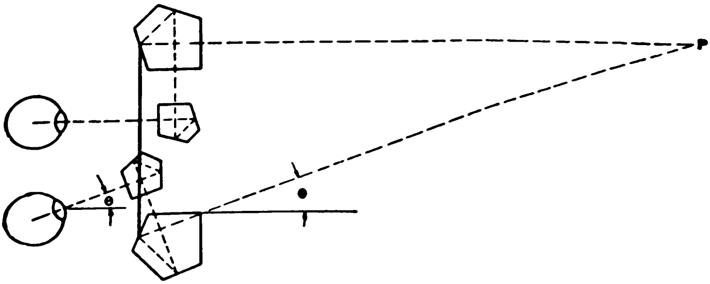


Figure 15–2.—How to increase the base-length of the eyes.

bar toward a distant object so that a line from the left-hand prism to the object is perpendicular to the bar as in figure 15–2. (left-hand prism is upper one in this figure).

The ray of light from the distant target to the left prism will be turned 90° and will travel inward along the bar and parallel to it. But a ray from the target to the right (lower) prism will make a rather large parallactic angle with the bar—more than 70 times the parallactic angle which the eyes would see at the same distance. This second ray will be reflected in along the bar, too, but will make an angle θ with it.

An additional pair of penta prisms could be used as shown in figure 15–2, or some other arrangement or mirrors and prisms could be used at the center of the bar, spaced as far apart as the eyes, to complete the "rangefinder." This arrangement would again turn each ray through 90°, directing each into one of the eyes. These two rays enter the eyes divergent by an amount equal to the parallactic angle θ, an angle which results from a 15-foot base rather than the short distance between the eyes. Thus, your eyes would see the object with the same parallactic angle as if you had spread your eyes 15 feet apart. This increases the maximum distance at which the eyes can detect differences in range by more than 70 times. The increased rangefinding ability can be found by dividing 15 feet by the distance between your eye pupils.

You have seen two ways in which the range and accuracy of the human rangefinder can be improved. The stereoscopic rangefinder combines both these methods. To see how this can be done, suppose that in figure 15–3 the rays emerging from the center prisms had been directed into the objectives of a pair of telescopes. Then the parallactic angle, already increased by the increase in base length, would be multiplied again by the magnifying power of the telescopes. Thus, for example, an instrument with a 15-foot base and a 24X telescope would have about 1,700 times the range sensitivity of the unaided eye.

In order to save space, some of the optical elements of the telescopes are mounted inside the rangefinder tube. A simplified arrangement would be like figure 15–3 which shows one side of the instrument.

The addition of the lens system in figure 15–3 magnifies the parallactic angle by an amount M. This changes the rangefinder formula to

$$\theta = 206{,}265\,\frac{BM}{R},$$

where B and R are expressed in yards.

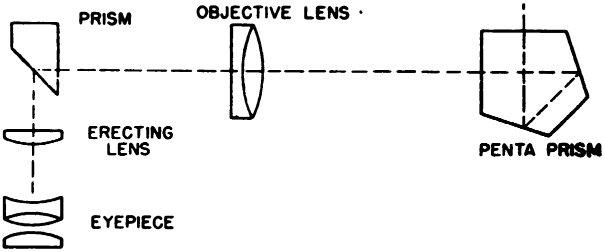


Figure 15–3.—One side of a simple stereoscopic rangefinder.

So far you have an excellent spotting glass by which you can tell very accurately which of two distant objects is farther away, but it will not tell you how far away. To measure this distance, another unit must be introduced into the instrument.

MEASURING WEDGE

In figure 15–4 a thin refracting prism or measuring wedge has been inserted in the instrument. The ray of light shown is coming from the penta prism, making an angle θ with the

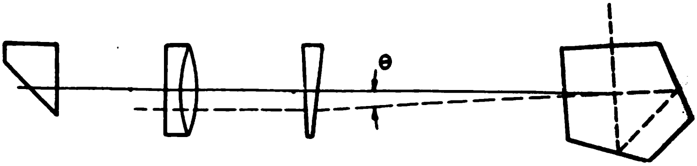


Figure 15–4.—Measuring wedge.

axis of the rangefinder. When the ray enters the thin prism it will be bent toward the thicker edge of that prism, thus reducing the angle between the ray and the axis of the instrument. To an operator looking through the eyepieces, the target would appear to have moved farther away. If the prism has just the right thickness, the ray of light will be bent parallel to the axis of the instrument. And for every parallactic angle, there will be a particular thickness of prism which will bend the rays exactly parallel to the axis.

But how is the operator going to tell when the ray is parallel to the axis? At the focal plane of the objective lens on each side of the instrument is located a reticle on which several sets of reference marks are engraved, as shown in figure 15-5.

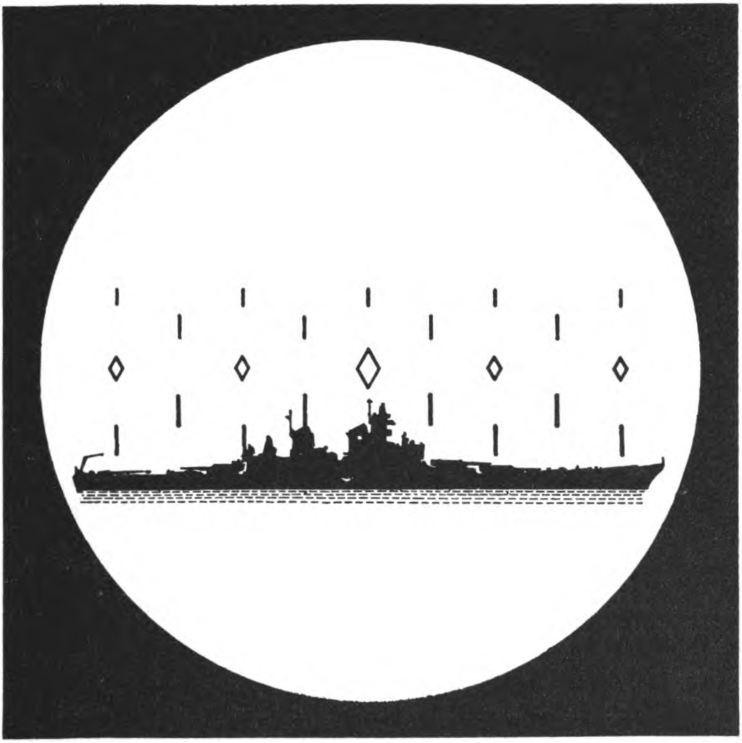


Figure 15-5.—Reference marks.

These reference marks are referred to as the WANDERMARKS or RANGING MARKS. These marks are in the center of the reticules on the optical axis of the lenses. When the eye pieces are focused so that the operator sees a sharp image of the target in each eye, he will also see a sharp image of the corresponding ranging mark. The two images in each eye will blend stereoscopically.

Now if the angle between the rays coming from the two RANGING MARKS is less than the parallactic angle between the rays from the target, the mark will appear to the observer to be more distant than the target. But if the angles are the same, the target and ranging mark will appear to be at the same distance. Therefore, when the ranging mark and the target appear to the operator to be at the same distance, he knows that the rays from the target have been bent by the measuring wedge enough to make them parallel to the axis of the instrument.

Operation of the Measuring Wedge

A rangefinder operator would be a busy man if he had to try out several different prisms in order to measure a range, so a convenient way of varying the amount by which a single refracting prism bends the light is provided by rotating the prism or MEASURING WEDGE.

If the prism is rotated with its thick edge up, as in figure 15–4, the ray will be bent forward or backward. Now if the prism is turned 90°, it will bend the ray just as much, but the bending will all be up and down with no forward and backward bending.

If the prism is turned to some angle *a* in between the vertical and horizontal, the bending will be partly up and down, and partly forward and backward as shown in figure 15–6.

In figure 15–6 the ray passing through the prism has been projected onto a screen to show the amount of bending. On the screen, *AO* measures the total amount by which the prism bends the ray. It will have the same length for any position of the prism. *OC* measures the amount of forward and backward bending and its length will depend upon the rotation of the prism. It is only the forward and backward bending that affects the apparent distance of the target. Rotation of the prism enables the operator to bend the ray forward and backward by any amount he desires.

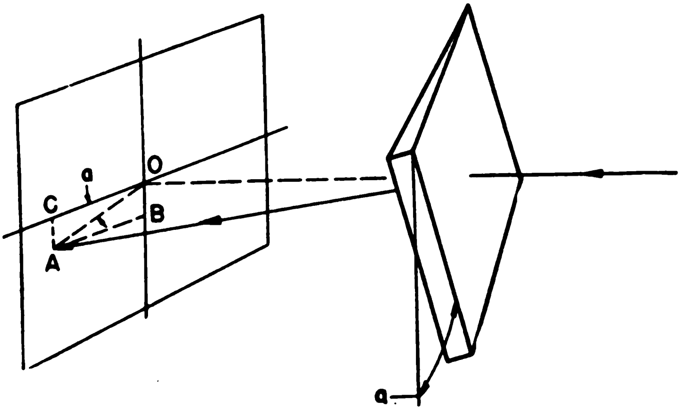


Figure 15–6.—Effect of rotation of the measuring wedge.

One difficulty remains. The upward and downward bending must be eliminated. This can be done by a second prism, if it is a duplicate of the first prism and is rotated an equal amount in the opposite direction. This will cause both forward and backward and up and down bending, but the up and down bending caused by the two wedges will be in opposite directions and will cancel out. The for-

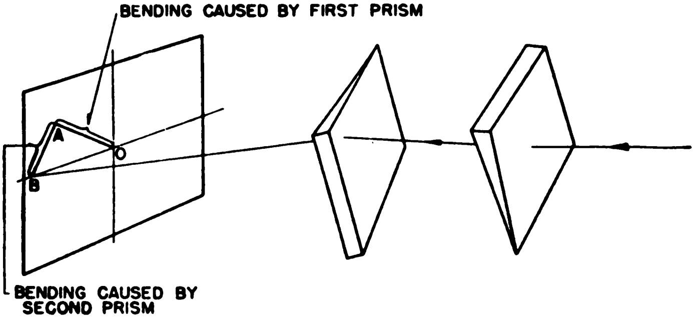


Figure 15–7.—Effect of rotating two wedges.

ward and backward bending of the two wedges will add together, as shown in figure 15–7. On the screen, the first prism causes bending *OA*, the second *AB*. The resultant movement is entirely forward and backward and amounts to *OB*.

Maximum bending to left will be obtained when the two prisms have their thick edges side by side, vertical, and to the left. One of the prisms rotates clockwise and the other counterclockwise, and the amount of bending to the left will decrease until, after 90° rotation, neither prism is causing any fore and aft bending. All of the bending of one prism is up, and the other down, and as the prisms continue to rotate, they will begin to cause bending to the right which will reach a maximum after 180° of rotation.

The amount of rotation of the prisms required to make the target and the ranging mark appear to be at the same distance measures the parallactic angle, thus, it measures the range. If a scale is mounted on one of the prisms to rotate with it, the scale can be graduated in yards of range, and the range can then be read directly.

STEREOSCOPIC RANGEFINDER

The structural frame of a rangefinder consists of three long tubes, one inside the other as shown in figure 15–8. The OUTER TUBE is simply a strong airtight cover to protect the optical and mechanical parts. Heavy wrappings of insulating material prevent fluctuations in the temperature of the working parts of the rangefinder. This tube is gastight and is kept filled with helium or nitrogen for the following reasons: (1) it keeps oxygen away from the lenses and prisms in order to retard aging of the optical glass and cementing materials; (2) since the gas is put into the instrument dry, it prevents the condensation of moisture on the inner surfaces.

The outer tube has a pair of rings around it, one near each end. These rings attach the rangefinder to its mount in a director or turret.

Mounted within the outer tube is the INNER TUBE which is

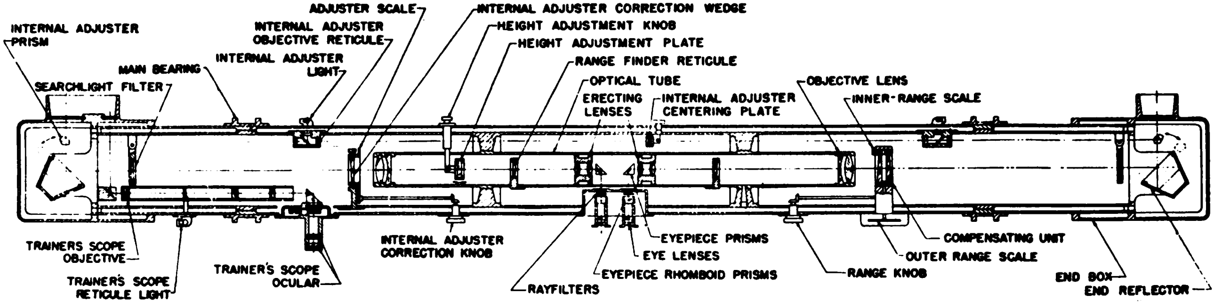


Figure 15-8.—Construction of a simple rangefinder.

the main structural frame of the instrument. It carries nearly all the optical and mechanical working parts. The only important exception is the eyepiece group which is fastened to the outer tube.

The inner tube is mounted inside the outer tube by means of two bearings. The right-hand bearing is constructed to permit a little movement back and forth along the axis of the rangefinder. Thus, if either of the tubes expands or contracts as a result of external stresses or temperature changes, the other tube will not be affected.

Within the inner tube is the OPTICAL TUBE, as shown in figure 15–8. This is a short rigid tube, machined from a steel forging. It contains those optical parts for which rigid alignment is necessary. These parts are the objective lenses, reticules, and the ocular prisms which bend the light toward the eyes. The optical tube is bearing-mounted in the inner tube so that it will not be affected by expansion and contraction.

The penta prisms needed in large rangefinders would be so large that they would be hard to manufacture, so two mirrors, mounted in a box frame, are used instead. The optical effect is the same as that of a penta prism. These assemblies are called END REFLECTORS and are attached by a rigid framework to the ends of the inner tube and protected by an airtight END BOX attached to the outer tube.

Optical glass windows are provided in the end box to admit light to the end reflectors. These windows are part of the optical system of the instrument and MUST NOT be moved. They are slightly wedge shaped so that they bend the entering rays by a very small angle. This bending is used in the last step in the alignment of the instrument at the factory. The end windows are rotated to take out any remaining error and are than cemented in place.

Rangefinder Adjustments

The first adjustable feature in the rangefinder is in the eyepiece which is focused to adjust the emerging rays to the degree of parallelism or convergence which is most comfortable for the operator's eyes. This adjustment is made separately for each eyepiece by rotating the focusing ring.

Do NOT close one eye when focusing the other eyepiece. Closing one eye changes the focus of the other. Have someone cover one end window of the rangefinder and then, with both eyes open, focus one of the eyepieces. If you know the proper setting for your own eyes, and know that the focusing scale of the rangefinder is correctly calibrated, you can instantly set the eyepieces to the proper focus for your eyes.

Although it seems obvious, operators sometimes forget that changing the focus will not remedy haze, darkness, or fogged end windows. The operator should determine the diopter setting (which is the adjustment we've been talking about), for his own eyes, on each instrument he uses, under the best possible conditions. He should use that predetermined setting when conditions are unfavorable for accurate focusing.

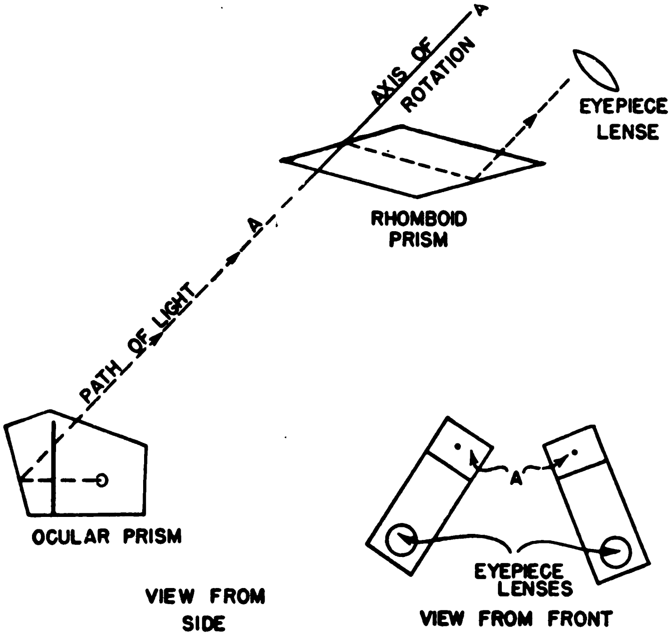


Figure 15–9.—Interpupillary distance adjustment.

Interpupillary Adjustment

Figure 15–9 shows how rhomboid prisms in a rangefinder enable you to adjust the spacing of the eyepieces. Since the image is reflected twice in each such prism (as shown), it emerges unchanged in direction. You can see that by pivoting the two rhomboid prisms on the axis *A–A* (lower right of fig. 15–9), you can adjust the distances between eyepieces. Moving the prisms on this axis does not change the length of the path of light, nor change the orientation of the image in any way.

A small knob or lever, located near the eyepieces, controls this interpupillary adjustment. If you do not know your own interpupillary distance, it might be a good idea to measure it now. Use an accurate interpupillometer and measure to the nearest ¼ millimeter. Then, whenever you use or inspect a rangefinder, you can set the interpupillary adjustment to the proper value for your eyes.

Height Adjustment

To maintain stereoscopic vision, the images arriving from the two end reflectors must be at the same height. This adjustment is made by tilting a piece of glass, as shown in figure 15–10.

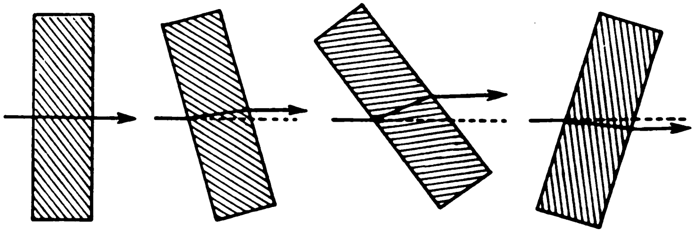


Figure 15–10.—Principle of the height adjuster.

When you refract a ray of light through a plate of glass with parallel sides, the ray is moved to one side without being changed in direction and the amount it is moved depends upon the angle at which it strikes the plate.

The height adjuster uses this principle. The device is simply a disk of glass, with parallel sides, inserted in the left-hand optical system. The disk is mounted on bearings so that it can be tilted in either direction. Tilting it, as shown in figure 15–10, will raise or lower the image of the target at the focal plane. A knob on the side of the rangefinder controls the tilt of the disk.

One way to make the height adjustment is to aim the rangefinder at some distant target such as the horizon. Set the range knob at minimum range. This should make it possible to break steroscopic vision and to see two separate images of the ranging mark and of the horizon. If one mark appears farther above the horizon than the other, move the height adjustment knob to equalize the distances.

Another method is to cover one end window of the rangefinder and, looking through the other eyepiece, train and elevate the rangefinder so that the bottom point of the ranging mark is just touching some target on the ship, such as a jackstaff. Now cover the other window and train the rangefinder slightly, without elevating or depressing it, to bring the ranging mark over the same target. With the height adjusting knob, make the bottom of the mark just touch the target.

Internal Adjuster Correction Wedge

The rangefinder is a precision instrument built with extreme care, but like any instrument it can get out of adjustment. Many things can cause it to lose its precise alignment. The most common trouble is change in temperature causing expansion and contraction of the various parts. When this happens, the instrument will give incorrect readings, and some means must be provided to compensate for the error. This is the purpose of the internal adjuster correction wedge.

Like the measuring wedge, the correction wedge is a thin prism of low power and is placed in the LEFT OPTICAL system outboard of the optical tube as shown in figure 15–8. Rotation of the correction wedge deviates the line of sight, both vertically and horizontally. The vertical component of deviation is the most useful; errors in horizontal alignment are corrected by adjustment of the height adjuster.

Checking the Rangefinder

The correction wedge is used when comparing rangefinder readings with some known distance. Suppose it is known that the distance to some point is 7,300 yards. A careful range is taken and the range scale reads only 7,000 yards. This 300-yard error must be eliminated.

The next step is to set the range scale at the known range to the target, in this case 7,300 yards. Now range on the target WITH THE CORRECTION WEDGE without touching the range knob. When the target and the ranging mark appear to be at the same distance, read the scale attached to the correction wedge known as the adjuster scale. Repeat this operation about ten times, keeping a record of the readings. Finally, set the average value obtained from the ten readings onto the adjuster scale. The instrument should now be in adjustment and ranging with the ranging knob should give correct values at any range. The correction knob is usually covered with a screw cap when not in use to prevent disturbing the setting.

A practical method of checking rangefinder ranges is against ranges obtained by a radar, as radar ranges are more accurate than rangefinder ranges.

Internal Adjustment

The methods already mentioned can be used for occasional checking of errors in the rangefinder due to variation of weather conditions provided a target is available. Since a target is not always available, some other means of checking the rangefinder must be provided.

The internal adjuster system also provides an artificial target, inside the instrument, which can be used to check the range scale. The placement of the parts of the internal adjuster system is shown in figure 15–8.

Figure 15–11 is a schematic diagram of the entire optical system of a rangefinder; this shows how the internal adjustment is made. Look at the internal adjuster system at the top of figure 15–11. The distance between the two adjuster objective lenses is equal to their focal length. Fastened to

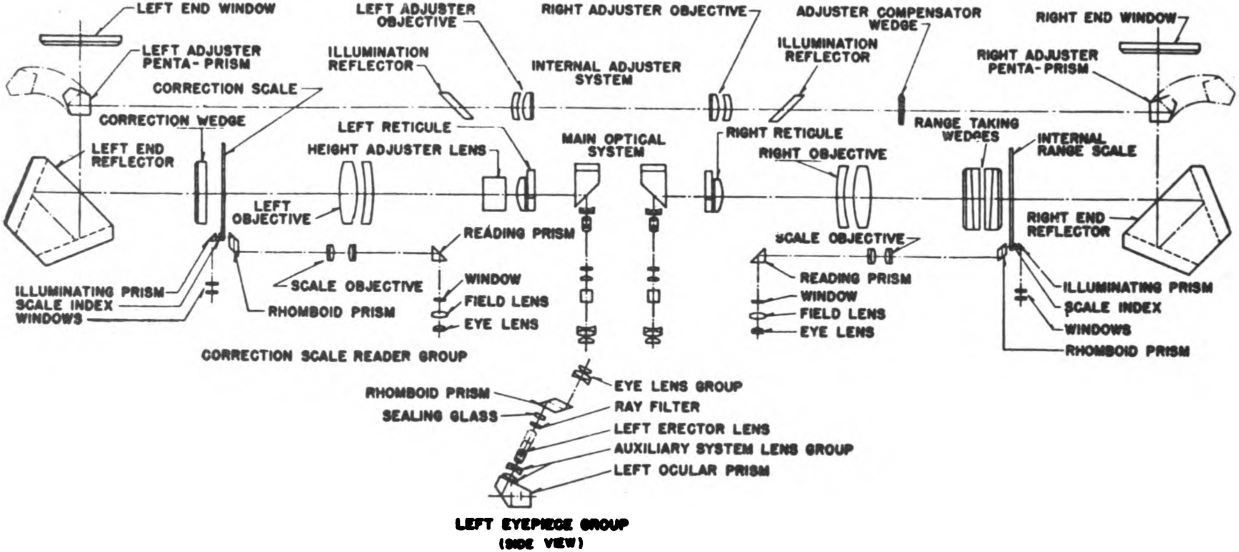


Figure 15–11.—Optics of the rangefinder.

each of the lenses is a reticle carrying a target mark, usually consisting of a pair of vertical lines. Each of the target marks is thus located in the focal plane of one of the lenses. Outboard of each lens is a transparent reflector plate.

Consider the left-end reflector. Light from the small internal lamp is reflected from the reflector plate and illuminates the left target mark. Since this mark is in the focal plane of the right objective, rays from the mark will emerge from the right objective parallel to each other. Some will be reflected by the right reflector and be lost, but some will pass through. At the same time the right target mark is illuminated by the right reflector and sends out rays which become parallel after passing through the left objective.

At each end of the adjuster tube is a small penta prism. Ordinarily these prisms are swung out of the way so as not to interfere with the operation of the main optical system. By turning the INTERNAL ADJUSTER DRIVE KNOB you can crank the two penta prisms into position, closing the shutters over the end windows to keep external light out of the system.

If the two objectives of the internal adjuster system are so mounted that their optical axes coincide, then the two sets of rays from the two internal targets will both be parallel to that axis, and after reflection at the two small penta prisms, the two sets of rays will still be parallel to each other. In stereoscopic rangefinder the operator will see one target with each eye, and the two images will fuse stereoscopically.

Remember that the deflection in the right-hand penta prism or end reflector is usually less than 90 degrees. This angle differs in different Marks of rangefinders. The angle of the right internal adjuster penta prism is always equal to that of the right end reflector. So there is one prescribed range at which the scale must be set in order to check its calibration with the internal adjuster system. The operator sets the range scale at this prescribed distance, and then sights through the eyepieces. In the stereoscopic rangefinder the image of the artificial target must appear to be at the same distance as the ranging mark on the reticle; if it does not, the operator must turn the correction knob until it does. The operator repeats this operation at least five times and sets the median correction on the range scale.

On the stereoscopic rangefinder, the internal adjustment is easier to make if the ranging mark on the reticle is centered between the two vertical lines of the artificial target. If it is not, turn the internal target adjuster knob (also called the collimator knob) to center it. The artificial target should never appear to touch the ranging mark; if it does it will interfere with your stereoscopic judgment.

Scales

Two range scales are provided on modern rangefinders, an external scale and internal scale. These scales are shown in both figures 15–8 and 15–11. The internal scale is a ring scale directly attached to the ranging wedge of the instrument and turning with it. Its position is always an accurate indication of the actual setting of the ranging wedge with no possibility of mechanical lost motion.

The internal range scale is read by means of an auxiliary reading telescope built into the rangefinder. Figure 15–11 shows that the reading telescope consists of an arrangement of lights and prisms to illuminate the scale, an objective lens, a collective or field lens, and an eye lens. The window shown in the illuminating system is to protect the airtight seal of the instrument.

The external scale is a second dial placed near the outside of the rangefinder so that it can be read through a window without the aid of artificial light, if the illuminating circuit for the internal scale should fail. Normally you will read the internal scale.

An occasional check should be made to see that the two scales are giving the same reading. If a discrepancy is found, it may indicate excessive lost motion or that the adjustment coupling between the external scale and the wedge is out of adjustment. In either case, repairs should be made by an optical repairman.

The internal adjuster correction wedge is read by means of an internal adjuster scale only, and has an optical system similar to that of the internal range scale. The adjuster scale is calibrated in UNITS OF ERROR.

Rangefinder Accuracy

Range measurement with the stereoscopic rangefinder is based on the ability of the operator to see whether the target and the ranging mark appear to be at the same distance. That is, accurate measurement depends upon the ability of the operator's eyes to detect whether the rays coming through the eyepiece from the target are parallel to the rays from the ranging mark.

The smallest difference of parallactic angle which the eye can detect is 12 seconds. This means that when the rays from the target and from the ranging mark appear to be parallel, they may actually make an angle of nearly 12 seconds with each other. Thus, when the rangefinder scale needs 10,540 yards, the actual distance to the target may be greater or less than 10,540 yards. The error may be any amount which does not change the parallactic angle observed at the eye by more than 12 seconds.

This distance by which the scale value of range is uncertain is called the UNIT OF ERROR. It is the distance in yards by which the range will change if the parallactic angle at the eye changes 12 seconds.

You can readily see that the value of the unit of error will become smaller as the base length and magnification of the instrument are increased; and figure 15–12 shows you that the value of the unit of error will be different at different ranges—the greater the range, the greater the unit of error.

It is easy to figure out the exact value of the unit of error from the formula:

$$e = \frac{58.2\ R^2}{BM\ 1{,}000^2}$$

or,

$$e = \frac{58.2}{BM}\left(\frac{R}{1000}\right)^2$$

In this formula, e is the range error in yards due to one unit of error:

B is base length of the rangefinder in yards;

M is the magnification of the rangefinder;

R is the range in yards;

58.2 is a constant valid only when the operator stereo-acuity is 12 seconds.

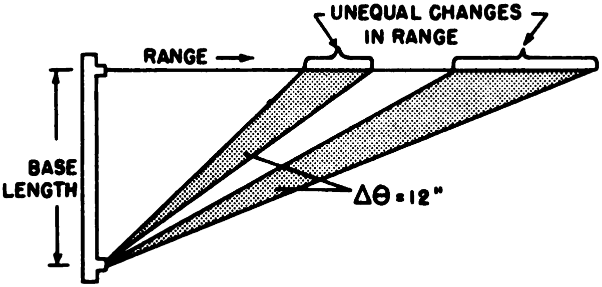


Figure 15–12.—How the unit of error increases with range.

The formula proves that the unit of error becomes less as base length and magnification of the instrument increase. In short, large rangefinders are more accurate than small ones. It also shows that the size of the unit of error in yards

RANGE YARDS	U. OF E. YARDS	RANGE YARDS	U. OF E. YARDS
1,200	0.7	14,000	95.0
1,500	1.1	16,000	124.1
2,000	1.9	18,000	157.1
2,500	3.0	20,000	193.9
3,000	4.4	25,000	303.0
4,000	7.8	30,000	436.0
5,000	12.12	35,000	594.0
6,000	17.5	40,000	776.0
8,000	31.0	45,000	982.0
10,000	48.5	50,000	1,212.0
12,000	69.8	....	....

Figure 15–13.—Values of unit of error for a typical rangefinder.

increases as the square of the range. This means that you can expect four times the error when you double the range. Figure 15–13 tabulates the values of the unit of error at different ranges for a 15-foot rangefinder with 24X magnification.

A-Curve

The *A*-curve shows the value in yards that a change of one unit of the adjuster scale will produce at various ranges. At least three objects *X*, *Y*, and *Z*, at different ranges are selected to get the readings necessary to plot this curve.

The operator takes an accurate internal adjustment check. Ten ranges are taken on object *X* and recorded. The adjuster scale is then deliberately set 10 units high and ten more ranges are taken and recorded. The same is repeated for a setting 10 units low. The internal adjuster scale has been offset a total of 20 units (+10 and −10). When the range difference obtained with these settings is found, the difference which has resulted from a change of 20 units can be divided by 20 to find the change produced by one unit. The same procedure is repeated for objects *Y* and *Z*.

The change in reading in yards that one unit of the adjuster scale will produce for targets *X*, *Y*, and *Z* is plotted against the rangefinder range to *X*, *Y*, and *Z*. From the curve drawn through these points the value in yards of one unit of the internal adjuster scale at any range can be determined as shown in figure 15–14.

Once the *A*-curve is constructed, if the rangefinder error at a given range is known, it is possible to determine the number of units the internal adjuster scale must be moved to correct for this range error, since the curve gives the change in yards which a change of one unit of the adjuster scale will produce at any range. To make this information readily available for any range, a *B*-curve, utilizing the data of the *A*-curve, is prepared. The *B*-curve is shown in figure 15–15.

B-Curve

To construct a *B*-curve, rangefinder ranges are taken on targets at various ranges where the range of each target is

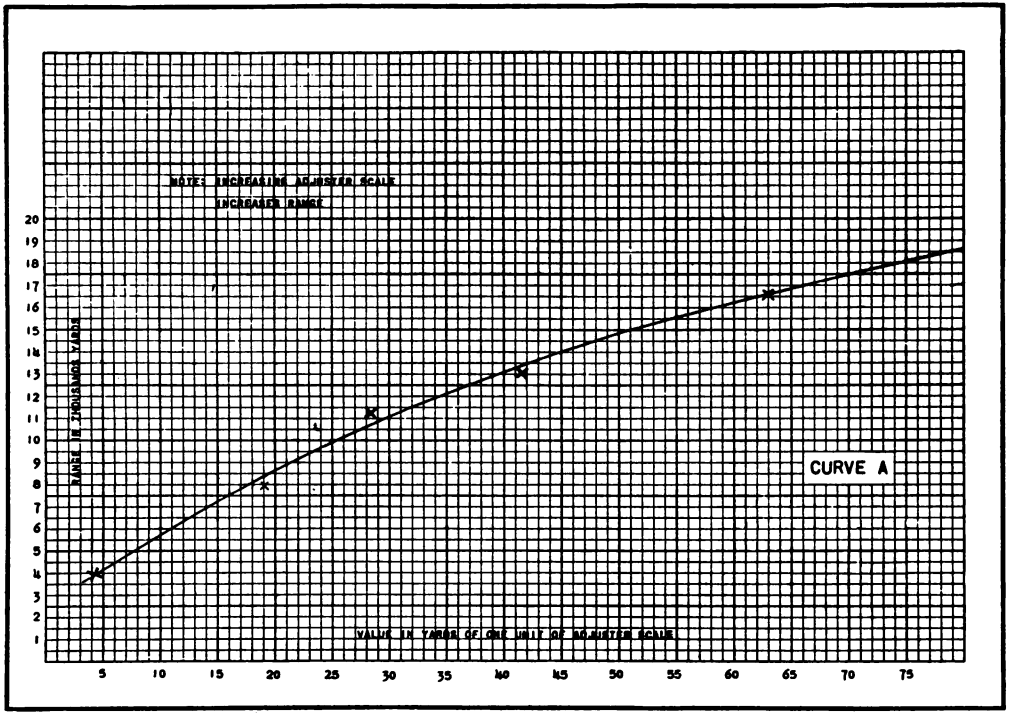
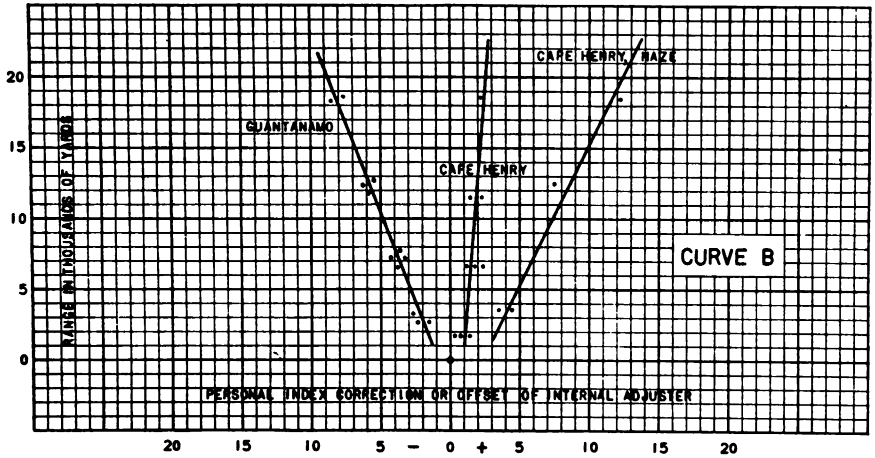


Figure 15–14.—Typical A-curve.



RANGE FINDER NO. 2

OBSERVER'S NAME Fred Smith FT3

CONDITIONS OF OBSERVATION			
LOCATION	GUANTANAMO	CAPE HENRY	CAPE HENRY
TIME OF YEAR	JAN. TO MARCH	JAN. TO JAN.	OCTOBER
WEATHER	GOOD, CLEAR	FAIR	HAZE
TEMPERATURE	87 TO 96	VARIOUS	69 TO 75
ETC.			

Figure 15-15.—Typical B-curve.

accurately known. The difference between the measured rangefinder range and the actual range of the target is the range error. Knowing (1) the error in yards, and (2) the value in yards of one unit of adjuster scale from the A-curve, the number of correction units required to make the rangefinder read true range is obtained by dividing (1) by (2). The resultant value plotted against the rangefinder range of the target gives a point on the curve. Several such points are plotted for each B-curve. For accurate results, widely spread ranges are taken on at least three different targets, under various conditions, as shown in the example of figure 15–15. A series of at least 10 ranges is taken on each target and the readings are recorded and averaged.

The B-curve of figure 15–15 is for one rangefinder operator. It is evident that internal corrections will be different (1) in the same locality under different weather conditions, (2) in different localities, and (3) for each different rangefinder operator. The B-curve shows corrections for Guantanamo and for Cape Henry under normal and hazy conditions Let's assume that a practice is to be fired in the Cape Henry area under Hazy conditions at 15,000 yards. It can be seen that +10 units is the index correction. This means that 10 units should be added to this operator's internal adjustment setting, since the index correction taken from the B-curve should always be applied to the internal adjuster scale setting after the internal adjustment has been made.

In practice, after the rangefinder operator has taken an accurate internal adjustment, the optical officer is notified of his scale setting. From the B-curve for the individual operator and the given rangefinder, the optical officer determines the index correction to be applied and notifies the rangefinder operator before he begins ranging. Changes in the index correction which may subsequently be required incident to a change of target, or an appreciable change of the range to the original target, will be sent to the operator by the optical officer.

In all calibrations the most important consideration is the accurate range to the target. In many localities special rangefinder calibration charts are provided with suitable targets at various ranges clearly identified. However, there is still the problem of obtaining an accurate position on the charts for own ship. This is done by standard navigational methods. It is to be noted that the anchorage bearings from ship's logs are not sufficiently accurate due to swinging of the ship; also, it must be remembered that if the rangefinder is located at some distance from the bridge, allowance must be made. Radar offers an excellent means for determining correct range to check against; radar range eliminates the need for checking the position of the ship.

SPOTTING WITH THE RANGEFINDER

The long base rangefinder is an ideal spotting instrument because you can tell clearly whether the fall of shots is short or over. But to do intelligent spotting it is essential that you understand the unit of error. Here is how it works. In addition to the ranging mark, the reticles of a rangefinder contain several other marks. Figure 15–16 shows a typical arrangement of one of the reticles.

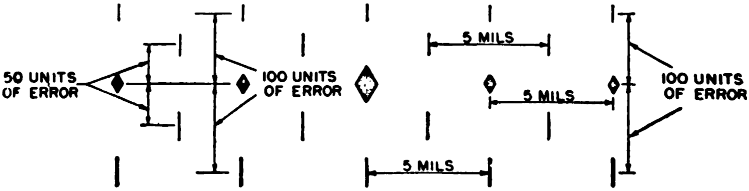


Figure 15–16.—Typical reticle pattern.

The large diamond in the center is the ranging mark. This large mark is located on the optical axis. The small diamonds are spaced the same distance from the axis on both reticles, thus rays coming from the corresponding diamonds on the two reticles are parallel to each other, and the small diamonds appear to be at the same distance as the ranging mark. The diamonds are spaced so that the angle between them at the eye is five mils. They can therefore be used for spotting a splash in deflection.

All the marks in any one horizontal row appear to be at the same distance, but the various rows appear to be at various distances. To the operator, the upper rows appear to be more distant than the diamonds; the lower rows appear closer than the diamonds. The marks in the first rows above and below the diamonds are so spaced that their apparent distance from the diamonds is equal to 50 units of error. The second rows from the diamonds appear to have a range difference of 100 units of error.

In ranging, the operator rotates the compensator wedge until the diamonds and the target appear to be at the same distance. He need not change this setting to measure the distance from the target of a burst or splash. By using the vertical marks for reference, the operator can estimate the spot in units of error, which can then be converted to the equivalent in yards for that particular range.

CARE OF RANGEFINDERS

Rangefinders are delicate instruments requiring very careful handling and operation to produce satisfactory results. Only regular rangefinder personnel should handle them. In cleaning rangefinders, dirt or grit should be removed from optical surfaces with a camel's hair brush to avoid scratching. Use of clean lens paper or chamois for wiping the optical parts is essential. Cleaning lenses with alcohol or ether should be restricted to experienced repair personnel, as both alcohol and ether dissolve the balsam used in cementing the lenses. Any repairs affecting the adjustment of the optical systems of a rangefinder should be accomplished only by qualified optical repair personnel.

QUIZ

1. The trigonometric function used in the triangulation formula for rangefinders is the
   a. sine
   b. cosine
   c. tangent
   d. cotangent
2. The accuracy of a rangefinder will increase if the base is
   a. increased and the range increased
   b. decreased and the range increased
   c. decreased and the range decreased
   d. increased and the range decreased
3. A prism bends light rays toward its
   a. farther edge
   b. nearest edge
   c. thicker edge
   d. thinner edge
4. The wandermark of the rangefinder is located at the focal plane of the
   a. objective lens
   b. erecting lens
   c. eyepiece
   d. end reflectors
5. What is the purpose of the second measuring wedge?
   a. To eliminate the up and down bending
   b. to eliminate the up and left bending
   c. To eliminate the down and left bending
   d. To eliminate the right and left bending
6. Each measuring wedge bends light rays an amount that
   a. is fixed
   b varies with rotation
   c. varies with range
   d. varies with the parallactic angle
7. How does the second measuring wedge move in relation to the movement of the first measuring wedge?
   a. The second wedge remains fixed
   b. The second wedge rotates with the first
   c. The second wedge rotates opposite to the first
   d. The second wedge rotates in a horizontal plane

8. The main reason why the end glass ports of a rangefinder should not be moved by ship's personnel is because
   a. they are fragile and break easily
   b. the gas seal will break
   c. the glass is polarized
   d. the glass is slightly wedge shaped, forming a prism
9. Which of the following rangefinder tubes is airtight?
   a. Optical tube only
   b. Outer tube only
   c. Inner tube only
   d. All of the tubes
10. Why are rangefinders charged with gas?
   a. To free the parts from dust
   b. To protect the parts for moisture
   c. To fix the temperature coefficient
   d. To prevent chemical reduction
11. The internal adjustment of the rangefinder is made by positioning the
   a. range wedge
   b. left adjuster penta prism
   c. correction wedge
   d. left adjuster objective lens
12. The internal adjuster scale is calibrated in
   a. seconds
   b. minutes
   c. mils
   d. arbitrary units
13. The internal adjuster correction wedge is used for
   a. internal reticle adjustment
   b. ranging on a known target range
   c. correcting optical tube focus
   d. adjusting the angular relationship of the measuring wedges
14. The stereo-acuity of the average rangefinder operator is about
   a. 6 seconds
   b. 8 seconds
   c. 10 seconds
   d. 12 seconds
15. The formula for unit of error, *e* is calculated in terms of
   a. yards
   b. mils
   c. seconds
   d. arbitrary units

16. If $B=15$, $M=24$, $R=20{,}000$ and the operator has a stereo-acuity of 12″, what is the unit of error in yards?
    a. 58.2 yards
    b. 69.8 yards
    c. 124.1 yards
    d. 193.9 yards

17. The unit of error increases with an
    a. increase in B and an increase in M
    b. increase in B and a decrease in M
    c. decrease in B and a decrease in M
    d. decrease in B and an increase in M

18. The A-curve is plotted in terms of
    a. unit of error
    b. units of adjuster scale
    c. units of range scale
    d. stereo-acuity units

19. To construct a B-curve, ranges should be known to at least
    a. two targets
    b. three targets
    c. four targets
    d. ten targets

20. A B-curve is plotted from range errors divided by
    a. unit of error
    b. units of adjuster scale
    c. units of range scale
    d. stereo-acuity units

CHAPTER 16

BATTERY ALIGNMENT

So far in this book we have covered basic electrical and mechanical computing units that may be encountered in all types of fire-control systems. The amplidyne circuits discussed may be applied to all amplidyne systems. The Mk 1A computer solves the same surface problem as the Mk 8 rangekeeper, but the Mk 1A has the added quantity of *RdE* to solve for in the air problem. The stable element used with the Mk 1A performs the same functions as the stable vertical; the major difference is that the stable element makes use of the outer gimbal to measure cross level and the inner gimbal to measure level, while the stable vertical uses the opposite gimbals in its measurement of the same quantities.

With all of the units discussed in the previous chapters we have solved the fire-control problem by ending up with gun orders to position the guns to hit the target. But will we? What about battery alignment? Even though the computing units are solving and transmitting the solution to the problem correctly, and no matter how well the elements of a gun battery and fire-control system function individually, they cannot function as a system unless they are properly aligned with each other.

Battery alignment is the procedure of aligning all instruments and guns to a common system reference point and plane. This procedure insures that all associated gun bores, lines of sight, radar beams, etc., are parallel when the dials are matched and if no parallax or ballistic corrections have been made. It also insures that they remain parallel throughout their operating motions and that all instrument dials and automatic control equipment measure these motions correctly with respect to the proper reference. To understand the process of battery alignment, certain terms must be learned if they are not already known. Following are some definitions used in battery alignment.

The HORIZONTAL is a plane tangent to the earth's surface or a plane parallel to such a plane.

REFERENCE PLANE for a battery is an arbitrarily chosen plane, usually within the ship, from which angles of elevation of all battery elements are measured. In practice it may be the plane containing one of the battery roller paths, or it may be an imaginary plane.

ELEMENT is a general expression for a gun, turret, director, etc.

TRUNNION TILT is the instantaneous inclination of the axis of the trunnions to the horizontal.

AXIS OF THE BORE is the extension of the axis of the gun bore. It is tangent, at the muzzle, to the trajectory of a projectile fired from the gun.

OFFSET CENTERLINE is a line parallel to the centerline of the ship. It is used as a reference line for measurement of angles of train.

ROLLER PATH INCLINATION is the angle between the plane of the roller path on which an ordnance element revolves and some other designated plane; it is expressed in terms of minutes of maximum angle and the relative bearing of the maximum inclination upward of the roller path plane.

BENCH MARK is a marked point on a ship for reference in checking alignment by using the line of sight.

TRAMS AND TRAM MARKS

A reference point for each turret and mount must be established in order to check gun train and elevation at sea. This reference is established when two marks or blocks, one on the fixed portion of the mount and one on the movable portion, are a definite distance apart when the mount is at a known angle. The tram blocks can be seen in figure 16–1.

When the reference is once established, then at any future time the mount can be trained or elevated until these two blocks are separated by the specific distance, whereupon the mount will be at the previously established angle, and the dial readings may be checked. The distance between the two blocks is established by a TRAM, and the blocks, as have been stated, are known as TRAM BLOCKS.

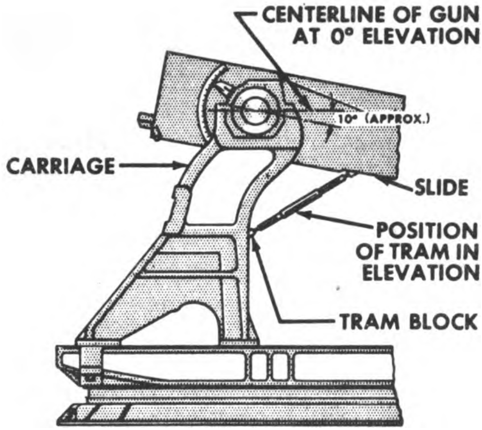

CENTERLINE OF GUN AT 0° ELEVATION
10° (APPROX.)
CARRIAGE
SLIDE
POSITION OF TRAM IN ELEVATION
TRAM BLOCK

Figure 16–1.—Tram mounted on a 5"/38 caliber gun for elevation reading.

The tram is a telescopic type and consists of an outer tube within which slides a separate bar. Motion of the bar into the tube is resisted by a coil spring carried in the tube part. A small window with an index mark is cut in the outer tube. Another index mark on the bar can be viewed through the window as shown in figure 16–2. When the marks on the tube and bar line up, the tram is properly set for checking the dial readings. This is done by inserting the tram between the two tram blocks and training or elevating the mount until the index marks line up. The dials should read the actual value of elevation or train as determined at the last check in dry dock. Figure 16–1 shows the tram bar in position between the tram blocks to check the elevation reading.

The accuracy of the tram may be checked by inserting it in the gage shown in figure 16–2. If the scribe marks line up, it is correct.

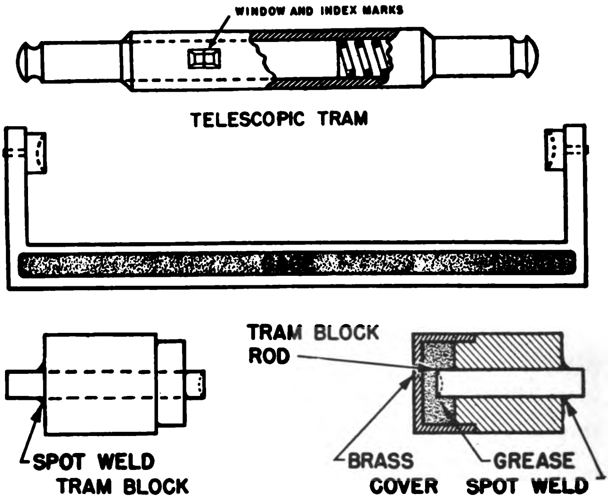


Figure 16–2.—Tram, tram gage, and tram blocks.

All mounts should be trammed at least once a month and the reading recorded for future use. These readings can be used as an indication of the stability of the battery alignment or of the elements in the mount. *Caution:* Mounts should be trammed with power OFF if manual operation is feasible.

ALIGNMENT OF SIGHTS

The initial step in battery alignment is to fix the relation of the optical line of sight through the gun sights to the axis of the bore of the gun. This is essential even if there is no fire-control system and the gun sight is used to point the gun.

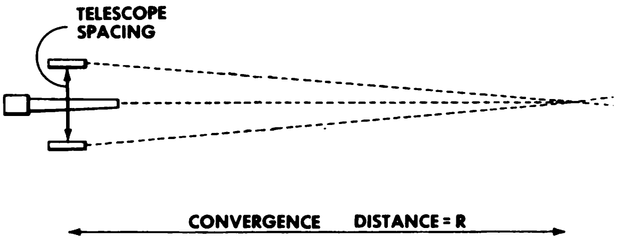


Figure 16–3.—Boresighting for convergence.

If a fire-control system is involved, the gun-sight alignment is also the first step in battery alignment. This is true because some of the other elements of the system will, for convenience, sometimes be checked to the gun sights instead of directly to the gun bore.

The pointer's and trainer's telescopes do not lie in the axis of the bore. Therefore, in firing short ranges in local control, they must be aligned so that their sighting axes converge with the extension of the bore axis at the target as shown in figure 16–3. Since the gun bore is only a few feet from the sights, the error which may be caused by parallel alignment is very small. Thus, for battle use, gun sights may be aligned either to the mean battle range for the battery involved or along parallel lines which converge at infinity.

BORESIGHTING

The object of boresighting is to establish either (1) convergence of the gun sight axis and the bore axis at a specified distance, or (2) parallelism of these axes. The range scale reading is zero and the deflection scale is set at midpoint or no deflection in both cases.

In order to adjust the sights in this manner, a boresight telescope must be used. This is a telescope which may be mounted in the bore of a gun and adjusted so that its line of sight coincides with the axis of the bore. Then by sighting through this telescope and through the gun sight telescopes simultaneously, the latter may be adjusted to obtain convergence or parallelism.

Boresight telescope assemblies are of two types designed for use on different guns. The assembly that is mounted by means of a breech bar is shown in figure 16–4; the other type is mounted within a cylinder which fits in the bore of the gun.

The boresighting operation is accomplished simply by bringing the gun to bear on the target so that the vertical crosshair of the boresight telescope may be aligned with a vertical mark on the target for a check in train. When the boresight is on, "Mark" is called. If the pointer's and trainer's vertical crosshairs are not on the target, they are

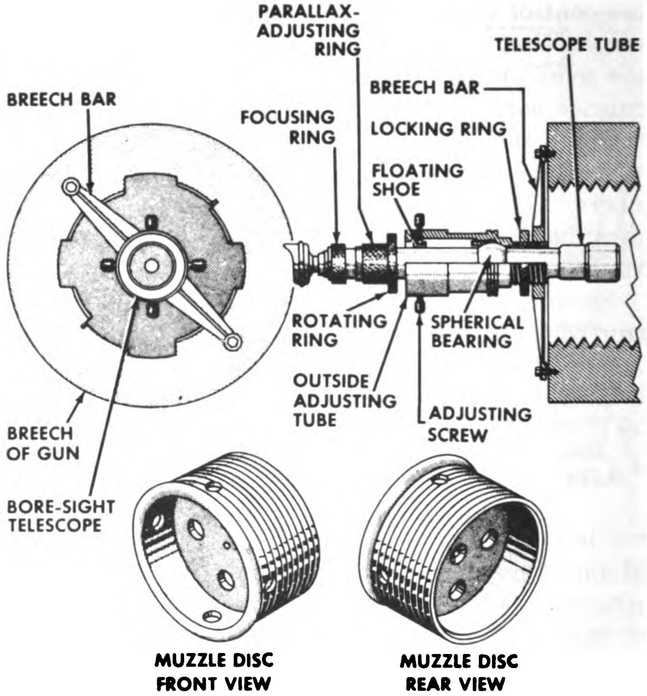


Figure 16–4.—Boresight apparatus.

adjusted until all vertical crosshairs are ON at the "Mark." Similarly, the horizontal crosshair of the boresight telescope is aligned with a horizontal mark on the target for a check in elevation.

TRAIN ALIGNMENT

The complete alignment of a ship's battery involves (1) mechanical alignment of the parts making up each element, and (2) alignment of the various elements with one another. Alignment of the various elements with one another is a primary concern of the gunnery officer, who should be familiar with methods employed in effecting the original alignment (in drydock). He should also make provision for routine checking and adjusting of the alignment, when at sea, by the Fire Control Technician.

Before proceeding with the alignment, it is necessary to insure that all elements are functioning correctly and that all transmission systems are properly adjusted. A routine transmission check is carried out just prior to the alignment check.

The purpose of system alignment in train is: (1) to insure that, with no parallax set in, the director lines of sight and the bore axes of the guns are parallel (in the horizontal plane) when the director is trained to any point, provided that the gun dial pointers are matched and sight deflection angle is zero. (2) To insure that, with the proper parallax settings made in director train and gun train order, the directors and gun lines of sight and the extensions of the gun bore axes converge on any given target at any range and at any bearing, provided that the gun pointers are matched and *Vs* and *Ds* are zero.

In order to accomplish 2, it is necessary to introduce parallax into both the director train and gun train order. It is, therefore, desirable to check the parallax system before beginning the alignment. Proper correction of parallax errors is of great importance aboard a modern ship because of the number of directors and the large horizontal displacements of guns and directors from the reference points.

HORIZONTAL PARALLAX

All train orders and measurements are based on a single horizontal reference point which, for single installations, is at the director, and for multiple installations is generally midway between the forward and aft directors on their centerline. The reference point to which parallax is measured on different types of ships and installations is shown in figure 16–5.

Parallax correction for a 100-yard horizontal base is developed in the computer Mk 1A and transmitted as a separate quantity to all guns, and in multiple installations to the directors not at or close to the reference point. The train-receiving unit at each mount receiving the quantity has a parallax mechanism which, by means of a simple gear

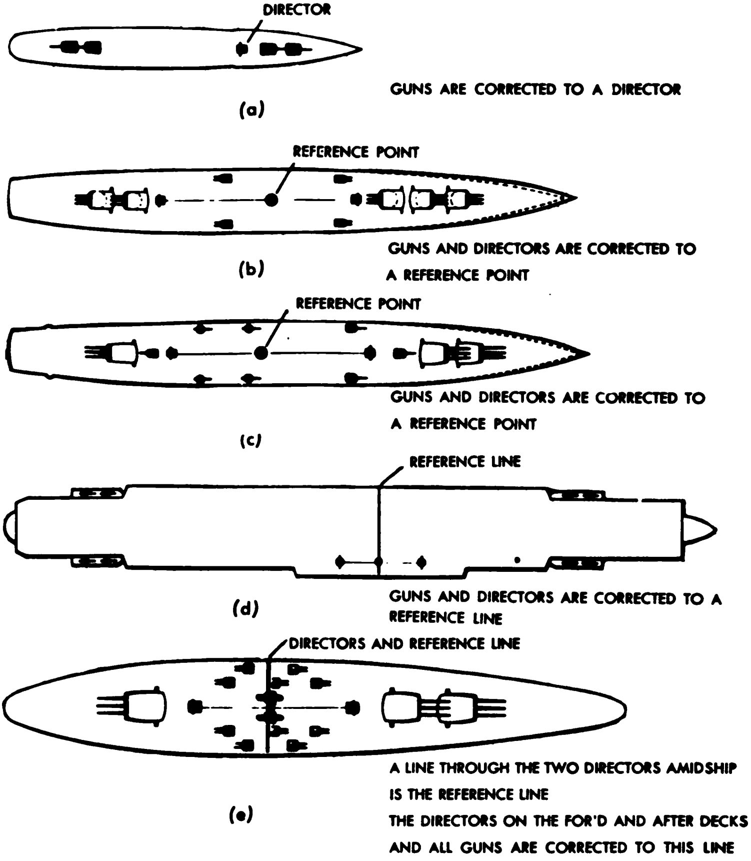

DIRECTOR
GUNS ARE CORRECTED TO A DIRECTOR
(a)
REFERENCE POINT
GUNS AND DIRECTORS ARE CORRECTED TO A REFERENCE POINT
(b)
REFERENCE POINT
GUNS AND DIRECTORS ARE CORRECTED TO A REFERENCE POINT
(c)
REFERENCE LINE
GUNS AND DIRECTORS ARE CORRECTED TO A REFERENCE LINE
(d)
DIRECTORS AND REFERENCE LINE
A LINE THROUGH THE TWO DIRECTORS AMIDSHIP IS THE REFERENCE LINE
THE DIRECTORS ON THE FOR'D AND AFTER DECKS AND ALL GUNS ARE CORRECTED TO THIS LINE
(e)

Figure 16–5.—Parallax is computed from a mean reference point.

ratio, changes the 100-yard correction to that corresponding to the actual mount displacement. This mechanism then applies the proper correction to the mount as required. In single installations such as in a destroyer, the reference point is on the director training axis, hence the director needs no parallax correction and has no parallax mechanism.

Parallax correctors on the guns and directors should be checked for:

1. Correct amount of parallax at various bearings and ranges.

2. Correct direction of applied correction.

If the parallax system is functioning properly, check the directors on their bench marks as follows:

1. Directors designed to receive level and cross level must have these values at zero while checking.

2. Parallax range must be set at infinity on the parallax corrector, at which setting no parallax correction is made.

3. Depress the line of sight to the bench mark.

4. Set the vertical wire of the pointer's scope on the bench mark and read the value on the train indicator dials. It should be the bench mark reading as indicated on the installed plate.

5. If the reading is incorrect, adjust the indicator to read the bench mark value.

Directors should be bench marked once a week and this should be recorded in the daily log or the battery alignment log.

ALIGNING THE GUNS WITH THE DIRECTOR

The preliminary alignment test is conducted as follows:

1. Establish telephone communication between the directors, plot, and the guns.
2. Set the switchboard for normal operation: director to plot to guns.
3. At the computer or rangekeeper, have the time motor switch OFF and the power switch ON.
4. Set *Vs* and *Ds* at ZERO on the computer or rangekeeper.
5. Set and LOCK level and cross level at ZERO.
6. Set *Vs* and *Ds* at ZERO at the guns; have the guns in manual or hand control.
7. Select a distant target on the beam. Train the director until the vertical wire (crosshair) is just off the target so that the motion of the ship will carry the wire across the target.
8. Obtain the range to the target by the most accurate means available and set this range on the computer or rangekeeper.

9. As the director line of sight swings on the target, the director trainer or pointer calls "Mark" (over the phone) to the guns. This procedure is continued, coming on the target always from the same direction, until the vertical wires of both gun and director telescopes are on the target together. When this occurs, record the reading of the director and the gun and then shift the director line of sight so it will again swing across the target. Then when the gun and director telescope vertical wires swing across the target together, another reading is obtained and recorded. The difference between the director reading and the gun reading is the error of alignment. To check for lost motion of the mount, train the mount to the target from both directions and read the difference from the dials. This difference is the lost motion.
10. If the average error between the gun and the director is greater than 2 or 3 minutes, the response setting of the mount must be corrected the proper amount and RECHECKED on the target.
11. When all corrections have been made, the complete system should be placed in AUTOMATIC and RECHECKED on the same target.

Should it be necessary to hold a train check at sea, the following may be used as targets: sun, moon, or stars. Range would be set to infinity so as to transmit zero parallax or the parallax mechanism may be placed in manual and the dials set to zero.

GUNNER'S QUADRANT

To obtain data for elevation alignment in dry dock, a gunner's quadrant is used. The correct use and reading of a gunner's quadrant is not difficult and accurate results can be obtained. The following general suggestions will prove helpful:

1. See that it rests firmly on a smooth surface but do not clamp it to the surface so tightly that the quadrant becomes distorted.

2. Make sure the arc of the quadrant is properly positioned; that is, if the elevation of a gun at a given bearing is to be measured, place the quadrant so that its arc is parallel to or coincides with the vertical plane through the axis of the bore.
3. Bring the bubble approximately to the center by sliding the arm along the arc; then clamp the arm.
4. Center the bubble carefully by means of the fine adjustment screw, allowing sufficient time for it to come to rest.

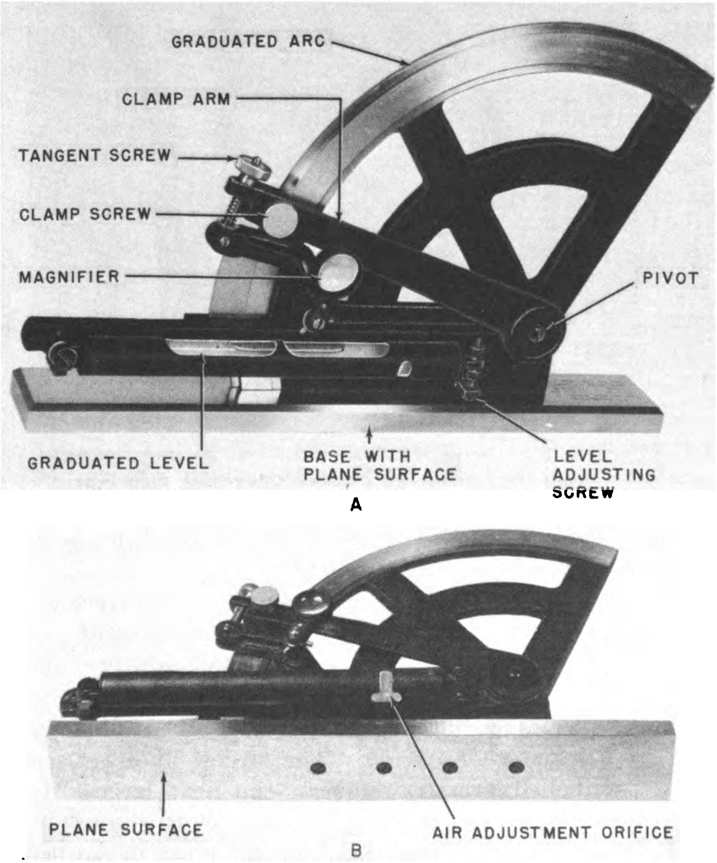


Figure 16–6.—Gunner's quadrant Mk 3 Mod 1.

5. Do not breathe on the bubble.
6. In any series of observations have one man use the quadrant for the entire set of readings.

There are two types of gunner's quadrants in use: the vernier type shown in figure 16–6 and the drum type shown in figure 16–7. They differ only in the types of scales used.

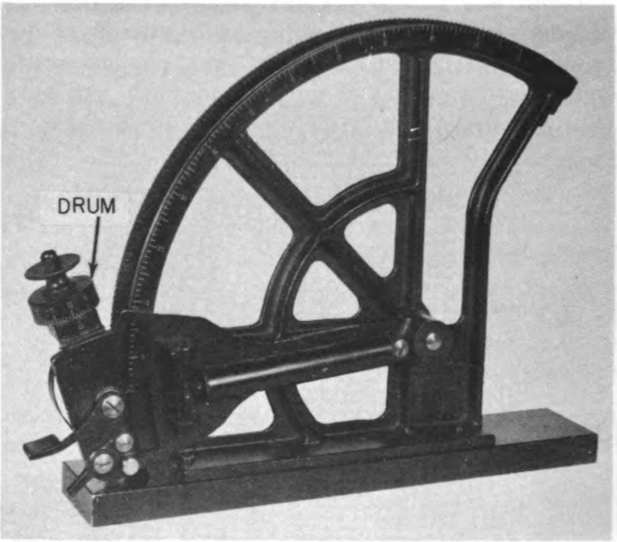


Figure 16–7.—The Mk 7 gunner's quadrant, drum type.

The most commonly used is the drum type and it is graduated in two scales as follows:

1. Arc or limb: numbers appear every 10 degrees and the largest lines between the numbers represent degrees. The next largest lines denote half degrees and the smaller lines each represent 10 minutes.
2. Vernier: The complete scale represents 10 minutes and is marked at 0 and 10. The largest lines between the numbers represent minutes, the next largest denotes 30 seconds, and the smallest denotes 10 seconds.

Before using, the gunner's quadrant must be adjusted so that it reads zero when exactly level. To check this:

1. Select a smooth plane surface which is nearly level. Draw a line on this surface and place the quadrant along the line. Center the bubble and read the quadrant.
2. Turn the quadrant around and set it on the line so that the inclination is measured in the opposite direction. Center the bubble and read the quadrant.
3. The average of these two readings should be zero; if it is not, the quadrant must be adjusted (adjustment screw) until this test shows that the average of the two readings is zero.

The procedure for obtaining drydock roller-path data with a gunner's quadrant is as follows:

1. Secure the quadrant to some smooth surface on the gun or director in such a manner that the line of the quadrant is parallel to the axis of the gun bore or the director's line of sight, and the pivot of the arm is forward.
2. Set the roller-path tilt corrector (if there is one) to zero tilt.
3. Elevate the gun to some convenient angle; this will make all readings positive. The difference between the readings is all that is important, so the amount of elevation is immaterial. In case of a director, the forward end of the quadrant must be shimmed (up) to obtain the same results, that is, to make all readings positive.
4. Train the gun or the director to 0°, level the bubble and read the quadrant. Repeat this process for every 10° or 15° of train. Record the inclination and the angle of train in each case. From these readings the actual relationship between the roller path and the horizontal plane is determined and the necessary compensations can be made for aligning all elements of the battery to a common reference. The relationship between any roller path and the horizontal is defined by the AMOUNT OF TILT AT THE HIGHEST POINT OF THE PATH AND THE BEARING OF THIS POINT, and compensating devices are built to correct in these terms.

Therefore, in order to interpret the results these two quantities must be determined for each roller path.

To use the gunner's quadrant afloat, following is the procedure:

1. Mount a gunner's quadrant on the reference director and on each of the guns, turrets, and directors to be checked. Station a qualified operator equipped with telephone at each instrument.
2. Train all elements on the same bearing.
3. The observer at the reference director adjusts his quadrant so that the bubble of the spirit level oscillates across the center mark of the level, and calls out "Mark" over the phones whenever the bubble is on the center mark.
4. The observers at the other stations adjust their quadrants until each is on "Mark." They verify the settings with several checks.
5. When all stations have reported on, the readings of all quadrants and the bearing are recorded.
6. All stations then train to a new bearing and repeat the procedure.

USE OF DIRECTOR BENCH MARK IN ELEVATION

1. Directors designed to receive level and cross-level angles must have these values set at zero while checking the director sights and dials.
2. Obtain the bench mark reading from the ship's records or from the engraving on the plate itself.
3. Train the director approximately on the bench mark.
4. Set the proper elevation bench mark reading on the elevation indicator dials by turning the pointer's handwheels.
5. Sight through the pointer's telescope and train the director until the vertical wire of the scope is on the bench mark.
6. The horizontal wire should now be on the mark also. If it is not, adjustment must be made between the elevation input to the telescope and the indicator dials until the horizontal wire is on, leaving the bench mark

reading on the indicator dials. Always adjust the pointer's scope (elevation input) first.

System Alignment in Elevation

The object of system alignment in elevation afloat is identical with the object of this alignment in drydock. This objective is attained by selecting some plane as the reference plane of the battery and adjusting elements of the battery so that elevation of all units, when measured from that plane or perpendicular, are equal.

In order to adjust the battery to this reference plane, it is necessary to compile data on the relative positions of all roller paths concerned. This is done by means of a HORIZON CHECK, which compares the elevation angles on the dials of the directors and guns when all are pointing on the horizon and on the same bearing.

Steps in performing a horizon check are as follows:

1. Choose a day when the ship has little roll and the horizon is clearly defined.
2. Man stations and phones.
3. Make sure that the synchro transmission system has been checked and that the director has been checked on its bench mark.
4. Use the reference director.
5. Record the roller path compensator setting of all stations. It should agree with the value determined during the last system alignment check in elevation.
6. Look up the height of the guns and directors and compute dip correction for each.
7. Set the switchboard to bypass the computer and transmit directly from the director to the guns. (If the switchboard does not permit such settings, it will be necessary to set the computer so that no corrections are introduced by its mechanism.)
8. If the test is to be performed with the boresight telescope, ship the telescope; in this case the setting of sight angle is immaterial. If the gun sights are to be used (and they normally will be), they must have been

boresighted recently. Set *Vs* and *Ds* in the gun to their respective ZEROS.

9. Train the director to a given bearing; elevate or depress the director line of sight so that it will move across the horizon as the ship rolls.
10. Train the guns and other directors to the same bearing as the reference director.
11. The pointers on all stations will depress their lines of sight, approximately on the horizon. When the reference director's sight passes the horizon, the pointer will call "Mark" and the other stations will turn their handwheels until their lines of sight cross the horizon with the reference director's "Mark." Always move the directors and gun lines of sight onto the horizon from the same direction to eliminate lost motion.
12. When all stations are on with the reference director, the elevation or depression as indicated by the elevation dials will be transmitted by phones to plot where it is recorded on a standard ship's form.
13. Repeat the foregoing process at 10° or 15° intervals throughout the train limits of each station.
14. Obtain the uncorrected station errors by taking the difference between reference director elevation and the individual station reading and recording the result for each bearing. The least difference will then represent the high point of the gun roller path with respect to the director roller path.

CALCULATING CORRECT COMPENSATOR SETTING

The horizon check is made with some setting already on the roller path tilt compensator. The tilt found by the check, therefore, is not the total inclination, but inclination which is in addition to that for which compensation has been made previously. This new inclination must be added vectorially to the inclination previously known to exist in order to determine the total inclination for which the compensator must be set. This may be done graphically.

It should be noted that the compensators are constructed to read the error rather than the correction. Thus, if the error is 11′ at 135°, the bearing scale is turned to 135° and the inclination of 11′ is set on the inclination scale and the adjustment is completed.

OTHER CHECKS

After a battery has been aligned in elevation, a test of the automatic follow-up system should be made. This involves training on a target, setting up the problem in the computer and positioning the gun in automatic (using computed gun orders), setting the sights accordingly to the *Vs* and *Ds*, and checking to see if the gun telescopes are on the target. If they are not on, the amount by which *Vs* and *Ds* must be changed from the computed value to bring the sights on the target represents the error of the system. To eliminate the trunnion-tilt errors when this test is made, there should be a little or no roll.

The necessity for alignment of the axis of the fire-control radar beam with the director optics should be mentioned. It is obvious that the radar line of sight must be parallel to the optical line of sight; otherwise false values of target position would be measured when tracking by radar. This alignment, the mechanical details of which vary with different types of radars and directors, is comparatively simple. Basically, it consists of placing the director exactly on the target optically and adjusting the position of the antenna until the pointer's and trainer's radar scopes give the optimum "On Target" indication. When this condition has been satisfied, the antenna is locked in place.

Note: Once the initial alignment is established, positive proof of errors must be present before any adjustments are changed. Too many times a well-aligned battery is fouled-up by placing too much reliance on any one check. All checks should be recorded in the Battery Alignment Log; also, any changes made to the original alignment must be logged as a future reference.

FIRING STOP MECHANISM

Theoretically, the battery is aligned when, with the dials matched and parallax on zero, all the lines of sight and the axes of all gun bores are parallel regardless of the ordered angles of gun train and gun elevation. In practice, however, the battery check is not complete until: (1) the firing cutout cams in each gun have been plotted, cut, and installed; (2) the firing stop mechanisms have been checked, with the cam installed, to insure that both the mechanical and the electrical firing circuits are interrupted properly whenever the guns move from a zone of safe fire to a danger zone.

The importance of this phase of the procedure cannot be overemphasized. The numerous casualties that have occurred because a ship has fired one of her guns into her own superstructure testify to the seriousness of any misalignment of the firing stop mechanisms. Some of these casualties resulted from negligence on the part of the ship's personnel: the cams were cut improperly and in some cases misaligned, or the firing stop mechanisms were inoperative through lack of preventive maintenance.

Firing stop mechanisms are designed to interrupt the mechanical and electrical firing circuits whenever the guns are trained or elevated to a position where firing the guns would endanger the ship's personnel or damage the ship. Firing stop mechanisms do not interfere with the free movement of the gun; this is done by the train and elevation limit stops.

The accuracy of the cam profiles and the adjustment of the firing stop mechanisms must be checked. The following is a suggested procedure; however, the voltmeter recommended can be replaced with an electric lamp of the correct voltage rating, if desirable.

1. Make sure that the gun is not loaded.
2. Lay the gun so that it is outside of a danger zone.
3. Complete the firing circuit as for local fire.
4. Connect a suitable standard voltmeter between the firing pin and ground, or across the terminal of the firing-cutout switch.

5. Firing circuit voltage should be indicated by the voltmeter, thus establishing continuity of the circuit.
6. Lay the gun so that it is within a danger zone; the voltmeter should now read zero.
7. Train and elevate the gun in and out of the firing zone at various points verifying that the operation of the firing stop switch, as indicated by the voltmeter, takes place at the proper points.
8. If percussion firing is also included in the cutout mechanism, check to see that percussion firing cuts out at the same points as those at which the switch in the firing circuit opens.

The preceding section has briefly presented the theory of firing stop mechanisms. But when it comes to plotting and cutting the cams, remember this: always consult the OP; there is no substitute for accurate information and exact knowledge.

QUIZ

1. The reference for measuring elevation angles with respect to the ship is the
   a. horizontal plane
   b. vertical plane
   c. deck plane
   d. roller-path plane
2. Where is the roller-path tilt corrector for the Mk 37 director of a typical destroyer installation located?
   a. There is no roller-path tilt corrector
   b. It is located in the stable element
   c. It is located in the director
   d. It is located in the computer
3. The tilt corrector that corrects gun roller-path inclination is located
   a. in the director
   b. in the stable element
   c. in the computer
   d. in each gun mount

4. The establishment of an offset centerline is a necessary step in accomplishing
   a. boresighting
   b. battery alignment in elevation
   c. check for parallelism
   d. battery alignment in train
5. The instrument used in obtaining roller-path data in drydock is the
   a. transit
   b. plumb bob
   c. gunner's quadrant
   d. stadimeter
6. The relationship between the plane of a tilted roller path and the true horizontal plane can be expressed in terms of the magnitude and bearing of the
   a. high point
   b. horizontal
   c. sine curve
   d. point of intersection

True and False

7. It is preferable to align a battery in elevation when the ship is in drydock and partially waterborne.
8. On a destroyer having only one director, the deck plane of the director roller path and the horizontal reference point is the director itself.
9. Before conducting an alignment check afloat, it is good gunnery practice to conduct a transmission check.
10. The gunner's quadrant is used exclusively to align guns.
11. During all parts of the train alignment it is essentially that parallax input to the battery element being checked should equal zero.
12. Inclination of a gun's trunnion axis to the horizontal is called trunnion tilt.
13. Convergence at a specified distance of the axis of a gun's bore and the axis of the pointer's and trainer's telescope is accomplished by boresighting.
14. To set a roller path inclination compensator it is necessary to know both the bearing of the high point and the amount of tilt.
15. The bench mark is used as a reference for checking gun alignment by using the line of sight.

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

How to Advance

1. True
2. False
3. False
4. False
5. True
6. True
7. False
8. True
9. False
10. False

CHAPTER 2

Computing Potentiometers

1. c
2. b
3. c
4. d
5. b
6. c
7. a
8. d
9. b
10. a
11. d

CHAPTER 3

Transformer Resolvers

1. d
2. c
3. d
4. a
5. b
6. a
7. b
8. c
9. c
10. a
11. c
12. d

CHAPTER 4

Mechanical and Electrical Conversion

1. c
2. b
3. d
4. a
5. False
6. True
7. True
8. False
9. False
10. True

CHAPTER 5

Linkage Computing Mechanisms

1. d
2. d
3. a
4. c
5. a
6. c
7. d
8. b
9. c
10. d
11. c
12. c

CHAPTER 6

Amplidyne Control Circuits, Power Drive Mk 4

1. b
2. b
3. c
4. b
5. a
6. a
7. a
8. c
9. a
10. d
11. d
12. c
13. b
14. a
15. c
16. d
17. d
18. b
19. a
20. d

CHAPTER 7

Amplidyne Control Circuits, Gun Director, Mk 37

1. b
2. d
3. a
4. c
5. a
6. c
7. c
8. c
9. b
10. d
11. d
12. d

CHAPTER 8

Gun Director, Mk 38

1. d
2. c
3. b
4. d
5. a
6. a
7. d
8. c
9. b
10. a
11. d
12. b
13. b
14. a
15. c

CHAPTER 9

Ballistics and Tables

1. d
2. b
3. a
4. c
5. c
6. a
7. b
8. c
9. d
10. a
11. d
12. c
13. a
14. c
15. c

CHAPTER 10

Solving Wind Corrections

1. b
2. a
3. c
4. d
5. c
6. d
7. c
8. d
9. a
10. d
11. c
12. c
13. c
14. b
15. c

CHAPTER 11

Relative Motion Problem

1. a
2. a
3. d
4. d
5. a
6. d
7. a
8. d
9. a
10. b
11. c
12. a
13. a
14. a
15. b
16. c
17. a
18. c
19. d

CHAPTER 12

Deck and Trunnion Tilt

1. b
2. a
3. d
4. d
5. c
6. d
7. a
8. d
9. c
10. a
11. b
12. a
13. d
14. d
15. d
16. a
17. a
18. c
19. c
20. b
21. d
22. b

CHAPTER 13

Gun Orders

1. b
2. d
3. d
4. c
5. d
6. a
7. c
8. c
9. a
10. c
11. a
12. a
13. b

CHAPTER 14

Generated Rates

1. a
2. c
3. c
4. d
5. a
6. a
7. c
8. d
9. b
10. b
11. d
12. b
13. c
14. b
15. d
16. c
17. d
18. a
19. a
20. c

CHAPTER 15

Rangefinders

1. c
2. d
3. c
4. a
5. a
6. a
7. b
8. d
9. b
10. b
11. c
12. d
13. b
14. d
15. b
16. d
17. c
18. b
19. b
20. b

CHAPTER 16

Battery Alignment

1. c
2. a
3. d
4. d
5. c
6. a
7. True
8. True
9. True
10. False
11. True
12. True
13. True
14. True
15. False

APPENDIX II

SURFACE FIRE-CONTROL SYMBOLS

To simplify references to the various quantities involved in the fire-control problem, and to parts of the rangekeeper concerned with the respective quantities, the system of nomenclature given below has been adopted. The fire-control symbols defined below should not be confused with the letters *A*, *D*, *L*, and *B*, followed by numbers, which are used to designate adjustment points, differentials, limit stops, and electrical reversing switches, respectively.

In the definitions given the following terms are understood:

a. The term "line of sight" is used to designate the line of sight from the director to the target.

b. The term "deck plane" means the horizontal reference plane of the ship.

c. The term "the horizontal plane" refers to the horizontal plane through the director sights. The solution given by the rangekeeper is based upon this plane.

Symbol	*Definition*
A	*Target angle*—Angle between vertical plane through fore and aft axis of target and vertical plane through the line of sight, measured in the horizontal plane clockwise from bow of target. $(A=180°+cB-Ct)$
cB	*Generated true target bearing*—Generated angle between north-south vertical plane and vertical plane through the line of sight, measured in the horizontal plane clockwise from north. $(cB=\Delta cB+jB)$
ΔcB	*Increments of generated true target bearing.*
jB	*Initial or corrective setting to generated target bearing.*
Br	*Relative target bearing*—Angle between the vertical plane through fore and aft axis of ship and vertical plane through the line of sight, measured in the horizontal plane clockwise from the bow. $(Br=B'r'+jB'r')$
cBr	*Generated relative target bearing*—Relative target bearing generated by rangekeeper as opposed to relative target bearing derived from director train. $(cBr=cB-Co)$

Symbol	*Definition*
Bw	*Wind direction*—Angle between north-south vertical plane and direction from which true wind is blowing, measured in the horizontal plane clockwise from north.
$B'gr$	*Gun train order*—Angle between fore and aft axis of ship and plane through gun axis perpendicular to deck plane, measured in the deck plane clockwise from the bow, without parallax correction. ($B'gr=B'r'+Dd'$)
$B'r'$	*Director train*—Angle between fore and aft axis of the ship and plane through the line of sight perpendicular to the deck plane, measured in the deck plane clockwise from the bow.
$cB'r'$	*Generated director train*—Director train as generated by the rangekeeper. ($cB'r'=cBr-jB'r'$)
$\Delta cB'r'$	*Increments of generated director train.*
$jB'r'$	*Correction to director train for effect of deck tilt.*
Co	*Ship's course*—Angle between north-south vertical plane and vertical plane through the fore and aft axis of the ship, measured in the horizontal plane clockwise from north.
Ct	*Target course*—Angle between north-south vertical plane and the vertical plane through the direction of target motion, measured in the horizontal plane clockwise from north.
Cws	*Wind angle*—Angle between the direction toward which true wind is blowing and the vertical plane through the line of sight, plus 180°, measured in the horizontal plane clockwise from the direction toward which the wind is blowing. ($Cws=180°+cB-Bw$)
Dd'	*Deck deflection*—Angle representing the total deflection in the deck plane; equal to gun train order minus director train. ($Dd'=Ds+Dz$)
Df	*Deflection to compensate for drift of projectile.*
Dj	*Deflection correction.* (Includes spots and ballistic corrections.)
Ds	*Sight deflection*—Angle between the vertical plane through the line of sight and vertical plane through the gun axis, measured in the horizontal plane. ($Ds=Dtwj+Df$)
Dt	Deflection to compensate for the relative movement of ship and target. ($Dt=jDt+KRdBs$)

Symbol	*Definition*
jDt	Partial deflection to compensate for the relative movement of ship and target. [$jDt=RdBs\ (Tf/R2-K)$]
Dw	Deflection to compensate for the effect of apparent wind on the projectile.
Dtw	$Dt+Dw$.
$Dtwj$	$Dtw+Dj$.
Dz	*Trunnion-tilt train correction*—Approximate correction in gun train order to compensate for tilting of the gun trunnions in cross level.
$E'g$	*Gun elevation order*—Elevation angle of the gun above the deck plane, measured in a plane through the gun axis perpendicular to the deck plane. ($E'g=L'+Vs+Vz$)
I. V.	*Initial velocity.*
K, $K1$, $K2$, *etc.*	*Constants*—Two or more constants in the same expression are distinguished by numbers.
L'	*Level angle*—Angle between the horizontal and deck plane, measured in a plane perpendicular to the deck plane containing the line of sight.
P. C.	*Powder charge.*
cR	*Generated present range.* ($cR=jR+\Delta cR$)
$^1/_{cR}$	*Inverse generated present range.*
ΔcR	*Increments of generated present range.*
dR	*Range rate.* ($dR=Yo+Yt$)
jR	*Initial or corrective setting to generated present range.*
$RdBs$	*Deflection rate.* Linear bearing rate measured at the target. ($RdBs=Xo+Xt$)
Rj	*Range correction*—Includes spots and ballistic corrections affecting advance range.
Rm	*Range prediction to compensate for changes from initial velocity.*
jRm	*Partial range prediction to compensate for changes from initial velocity.*
Rt	*Range prediction to compensate for relative movement of ship and target.*
Rw	*Range prediction to compensate for effect of apparent wind on the projectile.*
Rtw	$Rt+Rw$. ($Rtw=jRtw+K1\,Ywr$)
$jRtw$	*Partial* Rtw. [$jRtw=Tf(dR-K\,Ywr)$]
Rx	*Range prediction to compensate for deflection.* (exclusive of drift)
jRx	*Partial range prediction to compensate for deflection.* (exclusive of drift)

Symbol	*Definition*
Rmx	$Rm+Rx$.
$jRmx$	$jRm+jRx$.
$Rtwmx$	$Rtw+Rmx$.
$Rjtwmx$	$Rj+Rtw+Rmx$.
$R2$	Advance range. ($R2=cR+Rjtwmx$)
S	Target speed.
So	Ship speed.
Sw	True wind speed.
T	Time. (generated by a regulated time motor)
Tf	Time of flight. ($Tf-jTf+KR2$)
jTf	*Partial time of flight.* (cam output)
$Tf/R2$	*Time of flight divided by advance range.*
Vs	*Sight angle*—Angle between the gun axis and the horizontal plane, measured in the vertical plane through the gun axis. ($Vs=jVs+KR2$)
jVs	*Partial sight angle.* (cam output)
Vz	*Trunnion-tilt elevation correction*—Correction in gun elevation order to compensate for cross level.
Xo	*Component of ship's motion across the line of sight.* ($Xo=So \sin cBr$)
Xt	*Component of target motion across the line of sight.* ($Xt=S \sin A$)
Xw	*Component of true wind velocity across the line of sight.* ($Xw=Sw \sin Cws$)
Xwr	*Component or apparent wind velocity across the line of sight.* ($Xwr=Xo+Xw$)
Yo	*Component of ship's motion in the line of sight.* ($Yo=So \cos cBr$)
Yt	*Component of target motion in the line of sight.* ($Yt=S \cos A$)
Yw	*Component of true wind velocity in the line of sight.* ($Yw=Sw \cos Cws$)
Ywr	*Component of apparent wind velocity in the line of sight.* ($Ywr=Yo-Yw$)
Zh	*Cross-level angle*—Angle between the vertical plane through the line of sight and the plane perpendicular to the deck plane containing the line of sight; dip angle effect being neglected.

APPENDIX III

QUALIFICATIONS FOR ADVANCEMENT IN RATING

FIRE CONTROL TECHNICIANS (FT)

RATING CODE NO. 0800

General Service Rating

Scope

Fire control technicians maintain and repair fire control systems, including fire control radars and target designation equipment; make detailed mechanical, electrical, and electronic casualty analyses; test, operate, clean, lubricate, inspect, adjust, and calibrate fire control units; remove, repair, replace, and install or reassemble fire control components and systems; make transmission, computing, and rate tests on fire control systems; boresight guns and align guns or launchers and fire control systems.

Emergency Service Ratings

FIRE CONTROL TECHNICIANS A (Automatic Directors), Rating Code No. 0804 -- **FTA**

Maintain and repair fire control systems Mk 37, Mk 56, Mk 68, Mk 69, Gunars, surface fire control systems for calibre 6″ and above, and associated equipment.

FIRE CONTROL TECHNICIANS M (Manually Controlled Directors), Rating Code No. 0802 -- **FTM**

Maintain and repair fire control systems Mk 52, Mk 57, Mk 63, Mk 70, and Mk 51 director, and associated equipment.

FIRE CONTROL TECHNICIANS U (Underwater), Rating Code No. 0803 -- **FTU**

Maintain and repair fire control systems Mk 101, Mk 102, Mk 104, Mk 105, and Mk 106 or individual components thereof, and associated equipment.

FIRE CONTROL TECHNICIANS G (Missile Guidance Systems), Rating Code No. 0801 -- **FTG**

Maintain and repair guided missile fire control systems and associated equipment.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see *Manual of Navy Enlisted Classifications*, NavPers 15105 (Revised), codes FT–1100 to FT–1199.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
100 PRACTICAL FACTORS					
101 OPERATIONAL					
1. Demonstrate, under simulated conditions, the rescue of a person in contact with an energized electrical circuit; resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3	3	3	3	3
2. Read dials and set operating controls to predetermined values on fire control equipment	3	3	3	3	3
3. Demonstrate on fire control equipment to which assigned, operating procedures and techniques as required to:					
a. Perform operator's adjustments	3	3	3	3	3
b. Perform transmission, computing, and rate tests and report and record results	3	3	3	3	3
4. Demonstrate on target designation equipment of own ship, operating procedures and techniques required to:					
a. Perform operator's adjustments	3	3	3	--	3
b. Test and interpret qualitative performance of designate and repeatback channels	2	2	2	--	2
5. Compute corrections to compensate for operator and rangefinder errors	1	1	--	--	--
6. Demonstrate operating procedures and techniques on fire control equipment to which assigned, as required to train battle station and watch standing operators	C	C	C	C	C

	Qualifications for Advancement in Rating	*Applicable Rates*				
		FT	FTA	FTM	FTU	FTG
101	OPERATIONAL—Continued					
	7. Demonstrate operating procedures and techniques on target designation equipment of own ship as required to train battle station and watch standing operators	C	C	C	--	C
	8. Compute ballistics using standard forms and work sheets	C	C	C	--	---
102	MAINTENANCE AND/OR REPAIR					
	1. Identify electrical, electronic, and mechanical symbols used in schematic diagrams of fire control equipment	3	3	3	3	3
	2. Identify capacitors and resistors by RMA color codes	3	3	3	3	3
	3. Lubricate fire control equipment in accordance with lubrication charts	3	3	3	3	3
	4. Make tests of electrical fire control circuits for continuity, grounds, and short circuits	3	3	3	3	3
	5. Inspect and clean commutator and slip ring assemblies and replace brushes	3	3	3	3	3
	6. Make prescribed electronic tests of servo and computing circuits, using multimeters, tube testers, and cathode ray oscilloscopes, and report results	3	3	3	3	3
	7. Make operator's adjustments and checks to fire control radars	3	3	3	--	3
	8. Conduct shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles	3	3	3	--	---
	9. Trace circuits through fire control and sound-powered telephone switchboards and make repairs as necessary	2	2	2	2	2
	10. Perform all tests and adjustments necessary for proper operation of servo and computing circuits. Test					

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
102 MAINTENANCE AND/OR REPAIR—Con.					
synchros, interconnecting circuits, and switchboards and set synchros to electrical zero	2	2	2	2	2
11. Prepare a gun, launcher, director station, or target designation system for battery alignment (afloat) by aligning synchros and setting mechanical dials to reference points	2	2	2	--	2
12. Make internal adjustments and calibrations to fire control radars	2	2	2	--	2
13. Make standard electronic tests of radar circuits, using signal generators, multimeters, tube testers, and cathode ray oscilloscopes, and report results	2	2	2	--	2
14. Perform all shipboard maintenance on rangefinders not requiring the services of an opticalman	2	2	--	--	---
15. Prepare underwater fire control systems for battery alignment (afloat) by aligning synchros and setting mechanical dials to reference points	--	--	--	2	---
16. Trace circuits and test synchros and servomechanisms and make replacements, adjustments, and repairs	1	1	1	1	1
17. Test, remove, replace, and adjust mechanical parts of fire control and/or torpedo control equipment	1	1	1	1	1
18. Analyze failures and make repairs to servo and computing circuits	1	1	1	1	1
19. Lubricate and perform shipboard adjustments to gyroscopes used in fire control equipment	1	1	1	1	1
20. Conduct battery alignment tests and evaluate results	1	1	1	--	1
21. Boresight guns and align guns or launchers, directors, fire control radar antennas, torpedo fire control directors and indicators on tube mount, and target designation equipment. Test firing cutout devices for proper operation	1	1	1	--	1

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
102 MAINTENANCE AND/OR REPAIR--Con.					
22. Perform all tests and adjustments necessary for proper operation of radar circuits	1	1	1	--	1
23. Align underwater fire control systems. Test firing and firing cut-out devices for proper operation	--	--	--	1	---
24. Analyze results of transmission, alignment, computer, and rate tests to determine need for adjustment, replacement of parts, or repairs	C	C	C	C	C
25. Conduct all electrical tests on a complete fire control system	C	C	C	C	C
26. Analyze failures and effect repairs to target designation equipment	C	C	C	--	C
27. Conduct battery alignment and compute and apply corrections	C	C	C	--	C
28. Analyze failures and effect repairs to fire control systems	C	C	C	C	C
29. Analyze results of dummy director and error recorder tests and effect necessary repairs and adjustments	C	C	C	--	C
30. Conduct underwater fire control alignment and compute and apply corrections	--	--	--	C	--
103 ADMINISTRATIVE AND/OR CLERICAL					
1. Keep rough logs of periodic tests and maintenance	3	3	3	3	3
2. Make failure reports and keep ordnance histories	2	2	2	2	2
3. Use Ordnance Stock Catalogue	2	2	2	2	2
4. Maintain a Current Ship's Maintenance Project (CSMP) and prepare naval shipyard and tender work requests or job orders	C	C	C	C	C
5. Maintain supplies and spare parts and obtain replacements	C	C	C	C	C
200 EXAMINATION SUBJECTS					
201 OPERATIONAL					
1. Interpretation and interpolation of a dial setting into minutes, degrees, yards, or mils	3	3	3	3	3

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
201 OPERATIONAL—Continued					
2. Effects or electrical shock; method of resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3	3	3	3	3
3. Given course and speed of own ship and target, solve analytically for range rate and linear deflection (bearing) rate	2	2	2	2	2
4. Given course and speed of own ship and course, speed, and elevation of air target, solve analytically for range rate, linear deflection (bearing) rate, and linear elevation rate	1	1	1	--	1
5. Operating principles of stereo rangefinders. Methods used to measure operator and rangefinder errors and methods used to compute corrections	1	1	--	--	--
6. Variables and constants of initial ballistics	C	C	C	--	---
7. Elements of air and surface fire control problems	C	C	C	--	C
8. Variables and constants of underwater ballistics	C	--	--	C	---
9. Elements of underwater fire control problems	C	--	--	C	---
202 MAINTENANCE AND/OR REPAIR					
1. Types of information shown and meanings of electrical, electronic, and mechanical symbols used in schematic diagrams of fire control equipment excluding fire control quantities	3	3	3	3	3
2. RMA color coding systems for capacitors and resistors	3	3	3	3	3
3. Precautions to be observed in lubricating fire control equipment	3	3	3	3	3
4. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3	3	3	3	3
5. Methods of testing resistors, potentiometers, coils, transformers, capacitors, and electron tubes and					

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
202 MAINTENANCE AND/OR REPAIR—Con.					
application of each in voltage amplifier, phase inverter, power supply, oscillator, power amplifier, and rectifier circuits. Recognize electronic stages, power supply circuits, and coupling circuits	3	3	3	3	3
6. Function of each of the elements in gas-filled, vacuum, and cathode ray tubes	3	3	3	3	3
7. Calculate current, voltage, phase angle, impedance, and resistance in series and parallel circuits containing not more than a combination of four elements	3	3	3	3	3
8. Purposes of the following fire control radar operator's adjustments and checks: Intensity, sweep, focus, centering, receiver gain, receiver tuning, video gain, modulator frequency, range slew, range and train, and elevation zero checks	3	3	3	--	3
9. Properties of free and restrained gyroscopes and purpose of damping	3	3	3	--	3
10. Purpose and interpretation of shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles	3	3	3	--	--
11. Purposes of transmission, computing, and rate tests	3	3	3	3	3
12. Types, operating principles, and application of switching gear used in fire control and sound-powered telephone switchboards	2	2	2	2	2
13. Characteristics and use of synchros and methods of setting to electrical zero	2	2	2	2	2
14. Operating principles (excluding knowledge required *only* in research,					

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
202 MAINTENANCE AND/OR REPAIR—Con.					
engineering, and manufacture) of the following: Tuned coupling circuits, impedance matching, cathode followers, modulators and demodulators, oscillators, phase shifters, mixers, heterodyning, automatic gain control, frequency modulation, discriminators, automatic frequency control, integration and differentiation, counting circuits, saw-tooth generators, multivibrators, limiters, peakers, clampers, and half- and quarter-wave antennas	2	2	2	2	2
15. Methods of making gain, phase, balancing, bias, and zeroing adjustments of servo-loops found in computing and power-drive circuits	2	2	2	2	2
16. Use of tram bar, method of setting synchros to electrical zero, and method of positioning shafts by adjustable couplings	2	2	2	2	2
17. Types, application, and operating principles of electromechanical servo mechanisms	1	1	1	1	1
18. Purpose, operating principles, and adjustments of basic fire control mechanisms	1	1	1	1	1
19. Operating principles of computing circuits, servo-loops, and power-drive circuits	1	1	1	1	1
20. Method of mounting and alining a boresight telescope on a gun or launcher. Purpose and method of aligning sights to gun bore. Purpose and method of checking a director to a reference plane and reference point. Quantities set on inclination compensators. Methods for conducting train and elevation checks (afloat)	1	1	1	--	1

	Qualifications for Advancement in Rating	*Applicable Rates*				
		FT	FTA	FTM	FTU	FTG
202	MAINTENANCE AND/OR REPAIR—Con.					
	21. Purpose and operating principles of the following radar circuits: Transmitter, video amplifier, modulation generator, range unit, indicator unit, echo box, dummy antenna, power supply, wave-guides, antennas, voltage regulator, transmission lines, IF amplifier, RF amplifier, or preselector	1	1	1	--	1
	22. Method of setting up and purpose of dummy director and error recorder tests; information obtained and interpretation of results	1	1	1	--	1
	23. Method of aligning underwater fire control systems	C	--	--	1	--
	24. Purpose and method of the following radar checks: Double echo, receiver sensitivity, standing wave ratio, and transmitted power level	C	C	C	--	C
	25. Methods used in battery alignment (afloat and drydock). Use of gunner's quadrant. Method and purpose of static alignment. Principles involved in establishing bench mark and tram points. Method of computation of roller path inclination from horizon checks. Methods of train and elevation checks (afloat)	C	C	C	--	C
	26. Relationship of electrical and mechanical inputs and outputs of a radar, rangefinder, director, computer, stable element, and gun mount of a dual purpose battery	C	C	C	--	--
	27. Relationship of electrical and mechanical inputs and outputs of a launcher and missile fire control system	C	--	--	--	C
203	ADMINISTRATIVE AND/OR CLERICAL					
	1. Types, purpose of, and entries made in rough logs	3	3	3	3	3

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
203 ADMINISTRATIVE AND/OR CLERICAL—Con.					
2. Purposes and types of entries made in failure reports and ordnance histories	2	2	2	2	2
3. Types of information found in the following publications: Ordnance Pamphlets, Ordnance Data, Ordnance Circular Letters, Ordnance Handling Instructions, Ordnance Modification Instructions, Ordnance Material Letters, Ordnance Alterations, NavOrd Instructions, and NavOrd Notices	2	2	2	2	2
4. Purpose and scope of BuOrd Manual as stated in chapter 1	1	1	1	1	1
5. Information shown in Current Ship's Maintenance Project (CSMP), naval shipyard, and tender work request or job order	C	C	C	C	C
6. Physical requirements for range-finder operators	C	C	--	--	--
300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER Fire Control Technicians advance to Warrant Control Ordnance Technician and/or to Limited Duty Officer, Ordnance. As an alternate, Fire Control Technicians advance to Warrant Electronics Technician and/or to Limited Duty Officer, Electronics. *(See page iv-c of the "Quals Manual".)*					

APPENDIX IV

TRIGONOMETRIC FUNCTIONS OF AN ANGLE

Angle	Sin	Cos	Tan	Cot	Sec	Csc	
0°	0.0000	1.0000	0.0000	∞	1.000	∞	90°
1	.0174	.9998	.0175	57.29	1.000	57.30	89
2	.0349	.9994	.0349	28.64	1.001	28.65	88
3	.0523	.9986	.0524	19.08	1.001	19.11	87
4	.0698	.9976	.0699	14.30	1.002	14.34	86
5	.0872	.9962	.0875	11.43	1.004	11.47	85
6	.1045	.9945	.1051	9.514	1.006	9.567	84
7	.1219	.9925	.1228	8.144	1.008	8.206	83
8	.1392	.9903	.1405	7.115	1.010	7.185	82
9	.1564	.9877	.1584	6.314	1.012	6.392	81
10	.1736	.9848	.1763	5.671	1.015	5.759	80
11	.1908	.9816	.1944	5.145	1.019	5.241	79
12	.2079	.9781	.2126	4.705	1.022	4.810	78
13	.2250	.9744	.2309	4.331	1.026	4.445	77
14	.2419	.9703	.2493	4.011	1.031	4.134	76
15	.2588	.9659	.2679	3.732	1.035	3.864	75
16	.2756	.9613	.2867	3.487	1.040	3.628	74
17	.2924	.9563	.3057	3.271	1.046	3.420	73
18	.3090	.9511	.3249	3.078	1.051	3.236	72
19	.3256	.9455	.3443	2.904	1.058	3.072	71
20	.3420	.9397	.3640	2.747	1.064	2.924	70
21	.3584	.9336	.3839	2.605	1.071	2.790	69
22	.3746	.9272	.4040	2.475	1.079	2.669	68
23	.3907	.9205	.4245	2.356	1.086	2.559	67
24	.4067	.9135	.4452	2.246	1.095	2.459	66
25	.4226	.9063	.4663	2.145	1.103	2.366	65
26	.4384	.8988	.4877	2.050	1.113	2.281	64
27	.4540	.8910	.5095	1.963	1.122	2.203	63
28	.4695	.8829	.5317	1.881	1.133	2.130	62
29	.4848	.8746	.5543	1.804	1.143	2.063	61
30	.5000	.8660	.5774	1.732	1.155	2.000	60
31	.5150	.8572	.6009	1.664	1.167	1.942	59
32	.5299	.8480	.6249	1.600	1.179	1.887	58
33	.5446	.8387	.6494	1.540	1.192	1.836	57
34	.5592	.8290	.6745	1.483	1.206	1.788	56
35	.5736	.8192	.7002	1.428	1.221	1.743	55
36	.5878	.8090	.7265	1.376	1.236	1.701	54
37	.6018	.7986	.7536	1.327	1.252	1.662	53
38	.6157	.7880	.7813	1.280	1.269	1.624	52
39	.6293	.7771	.8098	1.235	1.287	1.589	51
40	.6428	.7660	.8391	1.192	1.305	1.556	50
41	.6561	.7547	.8693	1.150	1.325	1.524	49
42	.6691	.7431	.9004	1.111	1.346	1.494	48
43	.6820	.7314	.9325	1.072	1.367	1.466	47
44	.6947	.7193	.9657	1.036	1.390	1.440	46
45	.7071	.7071	1.0000	1.000	1.414	1.414	45
	Cos	**Sin**	**Cot**	**Tan**	**Csc**	**Sec**	**Angle**

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